

A CRITICAL STUDY OF CERTAIN SPECIES OF MUCOR

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A critical study of certain species of *Mucor**

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(WITH PLATES 17-20)

I. INTRODUCTION

The Mucorales have been widely investigated in Europe for the past half century; consequently much has been written about them and many have been described. In this country, however, such has not been the case; for, with the exception of several papers on some of the rarer genera, Blakeslee's (1904) important publications on the sexual reproduction of the group comprise the only American contributions to a knowledge of these most interesting fungi. The Mucorales include a large number of forms, exhibiting considerable variation; in fact, the individual plants are quite plastic, so that we may obtain striking differences within the species under different external conditions, such as medium, light, temperature and moisture. It is, therefore, extremely desirable, when dealing with descriptions of species in this group, to have full data on the most important growth conditions. Thus far this fundamental fact has been under-emphasized in the work on the mucors, especially on the taxonomic side.

The object of the present work is an attempt to standardize and unify the genus *Mucor* with reference to the morphology of its individual species and their cultural reactions. The lack of a general knowledge of the physiological attributes of the many species which have hitherto been described makes it desirable to give these forms a detailed comparative study in order that some fundamental standard for their future classification may be obtained.

The investigations, upon which this paper is based, have been carried on during the years 1913, 1914, and 1915 in the Cryptogamic Laboratory of the University of Michigan under the direction of

* Contribution No. 159 from the Botanical Department of the University of Michigan.

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II. HISTORICAL

I. CULTURE METHODS

In De Bary's *Morphologie und Physiologie der Pilze, Flechten und Myxomyceten* (1866) the application of cultural methods to *Mucor* is mentioned for the first time, in the following words: "Sie [*Mucor Mucedo*] wächst spontan und in den Culturen auf faulenden Früchten, Speisen, Zuckerlösungen und besonders üppig auf Mist." To Brefeld (1872), however, belongs the honor of having been the first to realize the necessity of employing the single spore culture method. On page 25 of the first Heft of his *Botanische Untersuchungen über Schimmelpilze*, we read the following: "Der Weg der Cultur einer einzelnen Spore unter lückenloser Verfolgung ihrer einzelnen Entwicklungsmomente, unter Vermeidung der vielen und zahlreichen Fehlerquellen, wie sie durch Invasion fremder Pilzsporen entstehen, kann allein die Basis für die Kenntniss und Klassifikation dieser Schimmelpilze abgeben." His method was very simple. He placed on a slide a single spore in a drop of freshly prepared horse dung decoction. The slides were observed directly under the microscope and when not in use were kept on a zinc plate covered with a bell jar standing in water to keep the air moist. He undertook a study of *Mucor Mucedo* (De Bary says "at my instigation") in order to learn whether De Bary was correct in his "apparently irregular pleomorphy" conception of the "collective so-called *Mucor Mucedo*." As a result he found that De Bary, owing to his crude culture method, had been dealing with an impure culture, having introduced *Chaetocladium* into the cycle of *Mucor Mucedo*.

G. Klebs (1898) does not go into detail with regard to his culture methods, nor does he mention a single spore culture. He used, for media, those substances which had proved the most favorable for the mold he was studying (*Sporodinia grandis* Link). These he found to be bread soaked with plum juice, slices of carrot and plum juice agar.

Oudemans and Koning (1902), making a study of the mycological flora of the soil of the Netherlands, give their technique in

detail. They used soil extract with 10 per cent. gelatin or 1.5 per cent. agar, but inasmuch as some fungi grew very slowly on these media, they added 2 per cent. of either saccharose or glucose. The following nutrient also proved very good in some cases: "wort 55, water 50," saccharose 2 per cent., gelatin 10 per cent., or agar 1.5 per cent. This medium always gave an acid reaction, but was used without neutralization. The manipulation may be outlined as follows: a fragment of humus from near the surface of the soil was introduced into a (previously sterilized) platinum crucible. About 1 c.c. of sterile water was then added, and the fragment of humus was triturated with a flamed glass rod, flattened at the end. A small amount of this infusion was transferred with a platinum loop to a test tube containing about 10 c.c. of water. The contents of the test tube were then emptied on a poured plate (Petri dish), which was inclined so as to allow the excess water to drain off. Their so-called pure cultures were made in one of the following ways: by cutting out a piece of the substratum with the organism on it; by transferring a fragment of the mycelium; or by transferring some spores to a newly poured plate.

In Hagem's (1908) method we are at once impressed with the fact that to him pure cultures from a single spore are prerequisites for any investigation. His method is as follows: with a platinum needle some spore material was transferred to a flask containing about 30 c.c. of sterile water. After a vigorous shaking to separate the spores, a few cubic centimeters of the dilution were poured into a second flask containing water. This was repeated once more and then 2 c.c. of this final dilution were poured into a Petri dish containing solid nutrient material, care being taken that the entire surface was moistened; the excess water was then poured off. After the cultures had stood for two or three days at room temperature, the cover of the Petri dish was removed and the plate was examined under the microscope for an isolated growth derived from a single spore. If such was found, it was cut out and transferred with a small amount of the substratum to a new dish. In his isolation of the soil-inhabiting forms, Hagem simply sprinkled a small amount of soil over three or four Petri dishes containing nutrient media. The one caution that he gives is that forms must be separated as soon as the

sporangia are formed; otherwise small forms are overgrown by the larger and more rapidly growing ones.

Blakeslee (1904), in his epoch-making study on the Sexual Reproduction in the Mucorineae, demonstrates his skill as a master of culture technique. In addition to the usual methods of gross and single spore culture, he devised a novel procedure for isolation of the two (plus and minus) strains. This consisted in teasing out an immature zygospore and placing it on a nutrient suitable for growth. After many unsuccessful attempts he discovered cases in which growth from both suspensors occurred in sufficient amount so that they (both) could be transferred to a fresh culture. In his investigations he employed many different kinds of media among which may be mentioned fruits, egg, potato, milk, urine, and bread.

It is difficult to appraise Lendner's (1908) method, which he does not present in detail. Presumably he used single spore cultures, but in discussing his methods, although he speaks of "dilution methods in use in bacteriology," he makes no mention of a single spore method.

For isolating soil fungi, Jensen (1912) mentions several methods, among which is described an iron tube for taking soil samples. This, however, proved unavailable in frozen soil. Thus he dug a trench 24 x 10 x 12 inches deep, and after removing the soil from the side of the trench with a sterile scalpel, he transferred the earth sample with the reflamed scalpel to a wide-mouthed bottle. In plating out his soil samples he either transferred particles of soil to poured plates directly, or else he made dilutions and then inoculated the poured plates with this dilution. He examined the inverted plates under the microscope, and when a germinating spore was found, he marked its location with a drop of India ink, cut it out, and transferred it to a new plate.

As Bainier (1883) and Schostakowitsch (1896, 1897, 1898) do not discuss their culture method in any great detail, it is impossible to judge whether they used a single spore as a starting point for their cultures. Schostakowitsch appears to have used bread chiefly as a substratum, while Bainier mentions having employed horse dung and also various sugar solutions in addition to bread.

Sumstine's (1910) reference to his cultural data is so frag-

mentary that it is impossible to know anything besides the substrata that he used. Among these, the only nutrient, with the exception of horse dung and meat, is bread.

2. TAXONOMIC

Inasmuch as the early history of the genus *Mucor* has been given in detail by Fischer (1892), we shall begin with the work of De Bary (1866). The latter included in *Mucor* many forms which have subsequently been shown to be distinct. For example, he attributed "an apparently irregular pleomorphy of reproductive organs" to *Mucor Mucedo*, including and confusing with it not only *Chaetocladium* but also *Thamnidium*. These somewhat startling results, as we have seen before, are to be explained by the crude culture methods in vogue in his day.

Brefeld (1872) made an important contribution to the systematic study of the Mucorales by showing that the polymorphism of previous authors did not exist. He it was who first gave us a clear conception of *Mucor Mucedo*, although he (at least in his early writings) included *Sporodinia*, *Phycomyces*, *Rhizopus*, *Chaetocladium*, and *Chaetocladium* in the genus *Mucor*, recognizing only one other genus, viz., *Pilobolus*. However, after studying *Chaetocladium* and *Piptocephalis* in detail he decided that they were both generically distinct from *Mucor*.

Van Tieghem (1873, 1875) has contributed more to our taxonomic knowledge of the Mucorales than any other person, but practically all of his work lies outside the genus *Mucor*, he having described and named only two species, *Mucor plasmaticus* and *Mucor circinelloides*. His work, therefore, in so far as the genus *Mucor* is concerned, consisted in defining the genus by removing all the closely related genera that were confused with it at that time. In his second publication (1875) we have the only reference to his idea as to the determination of the species of the genus *Mucor*. He says: "Depuis plus de trois ans que je m'occupe de cette famille, j'ai étudié et cultivé plus de trent espèces de *Mucor*, et souvent encore j'en découvre de nouvelles. Elles se répartissent en quatre sections. Le filament sporangifère demeure, en effet, simple chez les unes, tandis que chez les autres il se ramifie latéralement après avoir produit son sporange terminal. Ensuite,

suivant que, dans le premier, le filament sporangifère est doué ou non d'accroissement intercalaire, qu'il est élané ou trapu, suivant que, dans le second, le ramification s'opère en grappe ou en cyme, chacun de ces deux groupes se partage à son tour en deux sections. La monographie de genre *Mucor* et la description détaillée des nombreuses espèces qui le constituent est donc un travail d'assez longue haleine, qui doit faire l'objet d'une publication spéciale."

Schröter (1889) did not recognize *Circinella*, *Rhizopus*, and *Spinellus* as genera, but regarded them as subgenera under *Mucor*. Under his subgenus *Eumucor*, which was the genus as we now consider it, he gave but seven species, which are reduced to five when considered from our present knowledge of the genus. In Engler and Prantl's *Die natürlichen Pflanzenfamilien* (1892) Schröter still retained his all too comprehensive genus *Mucor*, having added a fifth subgenus *Pirella*.

Saccardo (1888) included descriptions of some seventy-eight species of *Mucor*, of which less than ten are now recognized as authentic species of *Mucor*. His only separation, or attempt at such, was a division into two groups, the first of which contains those forms in which the sporangia are slightly colored at maturity; the second, those which have hyaline sporangia at maturity. Under the first division he included a subdivision containing forms with ovoid spores.

Fischer (1892) was the first to monograph the genus *Mucor*, giving twenty-one species with an analytical key. He first divided them into three sections, according to whether they were simple, monopodially or sympodially branched. These he again divided: the first section was subdivided according to the nature of the turf—whether remaining erect or soon collapsing; the second and third sections were subdivided according to their method of branching. Fischer, referring to his key, says that inasmuch as the species have not been studied thoroughly, "die folgende Zusammenstellung kann deshalb nur als eine provisorische betrachtet werden."

Schostakowitsch (1896, 1897, 1898), in his studies on the Siberian mucors, found nine species, seven of which were new to science. He found that *Mucor Mucedo* and *Mucor racemosus*, which were supposed to be of common occurrence throughout the world, grew seldom if at all in Siberia.

Although Bainier (1883*a*, 1883*b*, 1903) described sixteen new species of *Mucor*, only six of these can be identified from his fragmentary descriptions. Moreover, not more than two of the six species were completely described.

Blakeslee (1904), in dealing with the genus *Mucor*, merely designated his different forms with Roman numerals, of which I and II were homothallic forms and III to VI inclusive were species heterothallic.

Hagem (1908, 1910*b*), limiting himself to a study of the air- and soil-inhabiting forms in Norway, isolated seventeen species, of which seven were new. Although he retained *Zygorhynchus* as a genus, he did not treat *Rhizopus* in like manner, but reduced it to a "Subsectio" under *Mucor*. In his key he retains Van Tieghem's grouping into forms with simple, racemosely, and cymosely branched sporangiophores.

Lendner (1908) has satisfied a long-felt need in his publication. In the preface to his work we find that he has limited himself to a treatment of the genera which contain many recently described species. He recognizes fifty-one species under the genus *Mucor*, including *Glomerula repens* Bain., *Parasitella simplex* Bain., *Zygorhynchus Moelleri* Vuill., and *Zygorhynchus heterogamus* Vuill. under the names *Mucor Glomerula* Lendner (Bain.), *Mucor parasiticus* Bain., *Mucor Moelleri* Vuill., and *Mucor heterogamus* Vuill. respectively. He, himself, collected but eighteen species, of which seven were undescribed.

In his analytical key to the species of *Mucor*, Lendner used the arrangement of Fischer for his three large groups, viz.: (1) *Mono-Mucor* (comprising the unbranched forms), (2) *Racemo-Mucor* (branching in racemes or corymbs), (3) *Cymo-Mucor* (branching in sympodial cymes). Under the first division he includes ten species, which are arranged according to the morphological characteristics, such as height, color, size of sporangia, sporangium wall, shape of columella, spores, etc. In the second group he has twenty species, arranged in much the same fashion as in the first section. The third group is the largest, having one more species than the second. This section, for the most part, is divided in the same manner as the two previous ones, but in two places the author makes use of physiological characteristics as a

basis for separation of species. In the first place, for example, he separates *Mucor Jansseni* from the remaining species by the fact that it grows poorly on "wort gelatin" but well on bread; in the second place, he separates *Mucor Rouxii* from the last four species by the fact that on either bread or "wort gelatin" it forms a short yellow down, while the remaining species form a turf 1-3 cm. tall.

Sumstine (1910), in his thirty page publication on the North American Mucorales, throws to the winds all the work of the late contributors to the group (Fischer, Hagem, Lendner, etc.). He separates from *Mucor* (Mich.) L., as ordinarily understood, the genera *Hydrophora* Tode (which had long been discarded for the name *Mucor*) and *Calyptromyces* Karst. (a genus founded merely on the fact that the sporangiophores are branched). In speaking of this last genus, Sumstine says: "This complex group contains some forty described species but the relationship of these species is not well known. There seem to be two modes of branching, monopodial and sympodial. This branching has been made the basis for the division into two groups, Racemo-*Mucor* and Cymo-*Mucor*. . . . This division, however, is uncertain and unsatisfactory." It is, in the writer's opinion, as unreasonable to maintain two genera, one for branching and the other for simple forms, as to separate species according to their mode of branching; for it has been found, during the course of this study, that the former distinction is practically as difficult as the one to which Sumstine objects. To give an idea of the confusion caused by the arrangement which this author proposes, let us consider a few cases. His *Mucor Mucedo* L. is the common *Rhizopus nigricans* Ehrenb., *Hydrophora stercorea* Tode is *Mucor Mucedo* Fresen., *Hydrogera obliqua* (Scop.) O. Kuntze is *Pilobolus crystallinus* (Web. & Wigg.) Tode, and *Calyptromyces ramosus* Karst. is *Mucor racemosus* Fresen. It is the writer's opinion that the only new things in this paper are names for plants which we fail to recognize under their new guise.

III. TECHNIQUE

I. COLLECTION OF MATERIAL

Collecting was begun in the autumn of 1913, when various kinds of dung, including that of the horse, cow, sheep, dog, rabbit, mouse, and squirrel, were brought into the laboratory, placed in moist chambers and watched for the development of mucors. Decaying plant material was also employed, and the following gave positive results: stems of decaying apple and grape (*Pyrus Malus* and *Vitis* sp.), mushrooms (*Collybia dryophila*, *Psalliota campestris*), wood and leaves (*Pinus sylvestris* and *Phlox* sp.), *Sphagnum* sp., tomato (*Lycopersicum esculentum*), carrot (*Daucus Carota*), Brazil nuts (*Bertholletia excelsa*), puff ball (*Calvatia* sp.), and oak root with mycorrhiza. In the case of the plant material used, the material to be tested was placed in a damp chamber until there was produced a growth of mold sufficient to insure a transfer to a poured plate.

In the belief that the *Mucor* soil flora might prove interesting, the author undertook a series of isolations, which consisted in obtaining surface soil from a great variety of stations. These samples, except in the cases cited below, were all taken in the vicinity of Ann Arbor, Michigan. The following method was used: Petri dishes were wrapped in paper, sterilized, then taken to the field, where they were unwrapped and opened only long enough to fill them with soil. The cover was then replaced and sealed with a gummed label, upon which were written the collection data. At the laboratory the earth was saturated with sterile water, a drop or two of which was then transferred to a poured plate by means of a flamed platinum needle. From this culture a pure gross culture could usually be obtained, from which, in turn, a single spore culture was eventually made.

All of the forms isolated (see TABLE I), with the exception of Nos. 2, 4, 5, 6, 68, 69, 70, 71, and 72, were collected in the vicinity of Ann Arbor. The first four of these nine collections were obtained in Chippewa County, Michigan, during the summer of 1914; the rest were collected in the Adirondack Mountains, Hamilton County, New York.

For collecting in the field, it has been found most convenient

to be provided with agar slants, and to make only rough cultures. In the case of soil forms a few small pieces of soil were placed, by means of a flamed platinum wire, in the tube; while in the case of coprophilus forms a gross transfer of hyphae with spores to the slant sufficed. These cultures were purified in the laboratory. TABLE I will give the data in a clear and concise manner.

TABLE I
COLLECTION DATA OF FORMS ISOLATED

No.	Date	Substratum	Species
1.	10/10/13.	Stem of decayed grape.	<i>Mucor griseo-lilacinus</i> sp. nov.
2.	7/ 9/14.	Decaying mushroom.	<i>Mucor Ramannianus</i> Moeller
3.	10/ 7/13.	Horse dung.	<i>Mucor griseo-lilacinus</i> sp. nov.
4.	8/19/14.	Porcupine dung.	<i>Mucor hiemalis</i> Wehmer
5.	8/15/14.	Bear dung.	<i>Mucor hiemalis</i> Wehmer
6.	7/13/14.	Moldy bone in woods.	<i>Mucor hiemalis</i> Wehmer
7.	10/12/13.	Horse dung.	<i>Mucor abundans</i> sp. nov.
8.	10/12/13.	Horse dung.	<i>Pilobolus longipes</i> Van Tiegh.
9.	10/27/14.	Sandy tilled soil, surface.	<i>Mucor abundans</i> sp. nov.
10.	11/18/13.	Horse dung.	<i>Mucor saturninus</i> Hagem
11.	10/19/13.	Sheep dung.	<i>Mucor griseo-lilacinus</i> sp. nov.
12.	11/20/13.	Squirrel (?) dung.	<i>Mucor griseo-cyanus</i> Hagem
13.	11/ 5/14.	Sandy wood soil, surface.	<i>Mucor hiemalis</i> Wehmer
14.	10/28/13.	Dung.	<i>Mucor abundans</i> sp. nov.
15.	3/14/14.	Rodent dung.	<i>Mucor griseo-lilacinus</i> sp. nov.
16.	10/23/13.	Horse dung.	<i>Mucor griseo-lilacinus</i> sp. nov.
17.	2/14/14.	Decaying wood.	<i>Absidia glauca</i> Hagem
18.	10/31/13.	Stem of decaying apple.	<i>Mucor varians</i> sp. nov.
19.	11/ 4/13.	Decaying tomato.	<i>Mucor abundans</i> sp. nov.
20.	2/19/14.	Decaying pine leaf.	<i>Mucor griseo-lilacinus</i> sp. nov.
21.	10/31/13.	Stable bedding and manure.	<i>Mucor varians</i> sp. nov.
22.	2/16/14.	Horse dung.	<i>Mucor abundans</i> sp. nov.
23.	1/31/13.	<i>Psalliota campestris</i> .	<i>Mucor griseo-lilacinus</i> sp. nov.
24.	11/22/13.	Dung.	<i>Mucor aromaticus</i> sp. nov.
25.	11/ 8/13.	Horse dung.	<i>Mucor abundans</i> sp. nov.
26.	11/20/13.	Dung.	<i>Mucor griseosporus</i> sp. nov.
27.	11/18/13.	Horse dung.	<i>Helicostylum piriforme</i> Bain.
28.	11/20/13.	Dog dung.	<i>Mucor abundans</i> sp. nov.
29.	11/22/13.	Decaying <i>Calvatia</i> sp.	<i>Mucor varians</i> sp. nov.
30.	11/27/13.	Old bones.	<i>Mucor griseo-cyanus</i> Hagem
31.	11/22/13.	Rabbit dung.	<i>Mucor abundans</i> sp. nov.
32.	11/22/13.	Dung.	<i>Mucor abundans</i> sp. nov.
33.	11/20/13.	Squirrel (?) dung.	<i>Mucor abundans</i> sp. nov. and <i>Chaetocladium Brefeldii</i> Van Tiegh.
34.	11/20/13.	Dung.	<i>Mucor proliferus</i> Schostak.
35.	10/23/14.	Oak root with mycorrhiza.	<i>Mucor lamprosporus</i> Lendner
36.	10/21/14.	Surface soil, hardwoods.	<i>Mucor varians</i> sp. nov.
37.	10/24/14.	Soil below surface, hardwoods.	<i>Mucor varians</i> sp. nov.
38.	10/27/14.	Surface, tilled soil.	<i>Mucor circinelloides</i> Van Tiegh.
39.	10/27/14.	Soil below surface in corn field.	<i>Mucor circinelloides</i> Van Tiegh.
40.	11/ 5/14.	Soil below surface in U. of M. Botanical Garden.	<i>Glomerula repens</i> Bain.

TABLE I—Continued

No.	Date	Substratum	Species
41.	11/ 5/14.	Sandy surface soil at edge of thicket.	<i>Zygorhynchus Vuillemini</i> Namysl.
42.	11/ 5/14.	Soil in greenhouse.	<i>Mucor circinelloides</i> Van Tiegh.
43.	11/ 5/14.	Soil from cold frame.	<i>Mucor circinelloides</i> Van Tiegh.
44.	11/ 5/14.	Soil in greenhouse.	<i>Mucor spinescens</i> Lendner
45.	11/ 5/14.	Soil in cold frame.	<i>Mucor circinelloides</i> Van Tiegh.
46.	11/ 5/14.	Surface soil in U. of M. Botanical Garden.	<i>Mucor varians</i> sp. nov.
47.	10/17/14.	Contamination in culture.	<i>Mucor plumbeus</i> Bonord.
48.	10/17/14.	Contamination in culture.	<i>Mucor christianiensis</i> Hagem
49.	10/17/14.	On decayed leaf.	<i>Mucor sphaerosporus</i> Hagem
50.	11/ 2/14.	Contamination in culture.	<i>Mucor sphaerosporus</i> Hagem
51.	10/ 6/14.	Decayed phlox leaf.	<i>Mucor plumbeus</i> Bonord.
52.	10/ 7/13.	Horse dung.	<i>Phycomyces nitens</i> (Agardh) Kunze
53.	11/23/14.	Contamination.	<i>Thamnidium elegans</i> Link
54.	11/10/14.	Soil in greenhouse.	<i>Mucor christianiensis</i> Hagem
55.	11/ 5/14.	Soil below surface in U. of M. Botanical Garden.	<i>Cunninghamella elegans</i> Lendner
56.	11/ 5/14.	Same data as No. 55.	<i>Mucor circinelloides</i> Van Tiegh.
57.	10/27/14.	Same data as No. 39.	<i>Mucor corticolus</i> Hagem
58.	10/27/14.	Same data as No. 39.	<i>Mucor varians</i> sp. nov.
59.	11/ 5/14.	Soil in greenhouse.	<i>Mucor christianiensis</i> Hagem
60.	11/ 5/14.	Same data as No. 46.	<i>Mucor abundans</i> sp. nov.
61.	3/25/15.	<i>Sphagnum</i> with germinating seeds.	<i>Mucor plumbeus</i> Bonord.
62.	4/ 7/15.	Decayed carrot.	<i>Mucor Ramannianus</i> Moeller
63.	3/25/15.	Decaying bean testas.	<i>Glomerula repens</i> Bain.
64.	6/ 5/15.	Contamination.	<i>Rhizopus arrhizus</i> Fisch.
65.	3/21/15.	Filter paper with date seeds in damp chamber.	<i>Syncephalis</i> sp.
66.	4/ 8/15.	<i>Pilobolus</i> sp.	<i>Syncephalis cornu</i> Van Tiegh. & Le Monn.
67.	4/ 8/15.	Horse dung.	<i>Mucor hiemalis</i> Wehmer
68.	8/17/15.	Decaying <i>Collybia dryophila</i> .	<i>Mucor saturninus</i> Hagem
69.	8/31/15.	Soil in mixed woods.	<i>Absidia caerulea</i> Bain.
70.	8/31/15.	Soil in mixed woods.	<i>Mucor corticolus</i> Hagem
71.	8/31/15.	Soil in mixed woods.	<i>Absidia glauca</i> Hagem
72.	8/31/15.	Soil in mixed woods.	<i>Mucor hiemalis</i> Wehmer
73.	3/12/15.	Rabbit dung.	<i>Mucor coprophilus</i> sp. nov.
74.	3/12/15.	Woodchuck (?) dung.	<i>Mucor hiemalis</i> Wehmer
75.	1/22/16.	Decayed Brazil nut.	<i>Mucor spinescens</i> Lendner
76.	1/16/15.	Fruit of <i>Kigelia pinnata</i> (brought from Java, 7/14).	<i>Mucor corticolus</i> Hagem
77.	1/22/16.	Decayed Brazil nut.	<i>Mucor christianiensis</i> Hagem
78.	1/22/16.	Decayed Brazil nut.	<i>Mucor plumbeus</i> Bonord.
79.	1/22/16.	Decayed Brazil nut.	<i>Rhizopus nigricans</i> Ehrenb.
80.	1/22/16.	Decayed Brazil nut.	<i>Circinella spinosa</i> Van Tiegh. & Le Monn.
81.	10/19/13.	Sheep dung.	<i>Pilobolus crystallinus</i> (Wig.) Tode
82.	10/31/13.	Stable bedding and dung.	<i>Pilobolus oedipus</i> Montagne
83.	3/26/14.	<i>Sphagnum</i> with germinating castor beans.	<i>Mucor botryoides</i> Lendner
84.	8/17/14.	Decaying mushroom.	<i>Sporodinia grandis</i> Link

2. ISOLATION

As a rule little difficulty was experienced in obtaining a pure gross culture, one or two transfers to poured plates usually sufficing to eliminate obvious contaminations. In a series of closely related forms, however, there is no certainty of a pure culture, unless the latter has originated from a single spore. For practically all purposes a medium of the following composition per liter was used:

Ammonium nitrate	1.0 gm.
Dihydrogen potassium phosphate	0.5 gm.
Peptone	0.5 gm.
Magnesium sulphate	0.25 gm.
Cane sugar	5.0 gm.
Agar agar	13.0 gm.

The advantage of this medium is that all forms tried have been found to grow on it, and that cultures kept on it through the summer months (June–September) retain their vitality, at least when kept in a cool place. For stock cultures the writer has lately used a formula given him by Blakeslee, viz.:

Agar agar	2.0%
Peptone (Witte)	0.1%
Dextrose	2.0%
Dry malt extract (Eimer & Amend)	2.0%

This agar gives a much more luxuriant growth than the first-mentioned medium, but its use for keeping cultures longer than six weeks has not been tried by the writer.

Single spore cultures were made by a modified Kauffman's (1908) method, which is essentially an isolation of a single spore by spraying a spore dilution on a poured plate. Capillary pipettes were made, fitted with a tiny loose-fitting cotton plug immediately below the nipple. These were then sterilized in a device made as follows: two pieces of corrugated sheet asbestos, two decimeters square, were fastened together with wire in such a way that the ridges met so as to form a series of tubes between the two pieces of asbestos. The pipettes, minus the rubber nipples, were then inserted in these tubes and the apparatus was placed on a tripod over a burner and heated. Later, after the apparatus had cooled, the rubber nipples were replaced very carefully to avoid displacing the sterile air in the pipettes.

Spore dilutions were made by transferring some spore material with a platinum wire to test tubes containing about twenty cubic centimeters of sterile water each. This dilution was then sprayed on poured plates, and if the pipettes were fine enough and the spores diluted sufficiently, it was always possible to find a single spore isolated from the rest. After ten to sixteen hours, depending upon the temperature, the plates were examined to note whether germination had taken place. For this purpose the Petri dish was inverted on the stage of the microscope and examined with the low power. If a solitary germinated spore was found, the location was marked with a drop of India ink, and later the spore, together with a tiny block of agar, was cut out by a spear-pointed needle and transferred to a new poured plate. The writer has always made it a practice to watch these cultures carefully and as soon as possible to make a transfer from the edge of the growth, in order to avoid the possibility of contamination through a neighboring spore delayed in germination. This last transfer was usually made within twenty-four hours after the spore had been removed. It seems almost unnecessary to add that all the cultures used have originated from single spore cultures made in the above-described manner.

3. HERBARIUM MATERIAL

In addition to depositing living cultures in the Cryptogamic Laboratory of the University of Michigan, a series of herbarium specimens was also prepared. Inasmuch as the method employed may prove useful to others it seems desirable to include it here. For the cultures, tall lipless beakers (500 c.c. capacity) were used, with a depth of about 3 cm. of bread. If fresh bread was used, no water was added, but if dried bread was used, water was added until the medium had the humidity of the former. For a cover half of a Petri dish was fitted with a thin layer of cotton batting, and then the preparations were autoclaved for three or four hours at fifteen pounds pressure.

Pure cultures were employed for inoculation, and then the cultures were placed in the dark, in order to secure a symmetrical development. The cultures were allowed to stand, not only until the maximum growth had taken place, but until the cultures were

thoroughly dried out, in the course of which process the medium and fungus had contracted and shrunk away from the glass. Thus it was a simple matter to remove them intact. Each specimen was glued to the bottom of a cardboard box, measuring $4\frac{1}{4} \times 3\frac{1}{2} \times 1\frac{1}{4}$ inches, the cover of which was fitted with a celluloid "window" $3\frac{1}{2}$ inches long and $2\frac{1}{4}$ inches wide. It is believed that with careful handling specimens prepared in this way will retain their characters for a long time. This opinion is not without evidence to support it, as the writer has examined some of his specimens which had been kept dry for one and one half years and also Ellis & Everhart's North American Fungi, Nos. 2454 and 972. In all cases the material was in such condition that its identity could be determined with certainty.

IV. EXPERIMENTAL

The experimental work was undertaken in the hope that the results, supplemented by the morphological characters, might form a basis for the separation of species. It was desired to know whether forms morphologically similar would react similarly to the same cultural conditions, and whether forms whose morphology might lead us to believe them distinct might exhibit, or manifest, their close affinity in their cultural characteristics under the same conditions. Such has been found true only to a certain degree, but the results of the experiments are believed to be of value in the taxonomic part of this study. Consequently, experimental data have been freely used in the commentary on the individual species.

A uniform system of tabulation has been used throughout the series of experiments, in order to admit of easy comparison and also to avoid unnecessary confusion. The numbers given in the first column of TABLE I are used in all succeeding tables and throughout the work in the same way. It will be noticed in TABLES II and III that for each *Mucor* number there are two columns, the first containing Arabic, and the second Roman numerals. The former gives the height (length of sporangiophores) in millimeters, the latter the growth (judged by mass appearance), IV being excellent, III good, II fair, and I poor. It should be added that the presentation of results has been condensed on account of lack of space; hence, in the case of each medium, only the maxi-

num growth is given irrespective of time. Furthermore, in any consideration of the numbers in the tables, it must be borne in mind that these numbers are liable to be misleading when interpreted from a standpoint of medium exclusively, because they include the inherent tendency of the species. To be specific, *Mucor griseosporus* has been found by the writer to be more plastic than other species; for example, it varies from 8 mm. to 20 mm. in height according to the medium used, while *Mucor spinescens* is always a low-growing form, heights varying only from 2 mm. to 8 mm. having been obtained.

TABLE II

HEIGHT AND GROWTH OF MUCORS WITH MISCELLANEOUS GELATIN MEDIA

Media	Mucor No. 34		Mucor No. 5		Mucor No. 4		Mucor No. 1		Mucor No. 7		Mucor No. 40		Mucor No. 16		Mucor No. 12		Mucor No. 21		Mucor No. 44	
	Ht.		Ht.		Ht.		Ht.		Ht.		Ht.		Ht.		Ht.		Ht.		Ht.	
	C.		C.		C.		C.		C.		C.		C.		C.		C.		C.	
Levulose..	35	IV	15	III	15	III	15	III	15	III	15	III	15	III	10	II	5	II	8	II
Dextrine..	35	IV	15	III	15	III	15	III	15	III	15	III	15	III	8	II	5	II	8	II
Glucose (a)	25	IV	17	III	16	III	15	III	14	III	15	III	12	III	10	II	9	II	3	I
Glucose...	30	IV	12	III	11	III	10	III	13	III	12	III	10	III	4	II	7	II	6	I
Dung ext.	20	IV	17	III	20	III	12	III	20	III	8	II	5	II	9	II	5	II	5	I
Raulin (a)	30	IV	11	III	11	III	15	III	5	II	18	III	8	II	5	II	9	III	3	I
Maltose..	20	IV	12	III	11	II	9	III	4	III	11	III	10	III	6	II	5	II	5	I
Lactose...	20	IV	10	II	15	III	15	III	8	III	5	II	4	II	3	II	5	II	3	I
Beef broth	36	II	12	II	14	II	11	II	9	II	7	II	9	I	9	II	8	I	5	I
Inulin...	10	III	8	II	12	II	8	II	10	II	5	II	8	II	7	II	3	II	3	I
Sucrose...	—	—	—	—	11	III	5	II	10	III	9	II	5	II	5	II	5	II	2	I
Inorg. salts	—	—	—	—	9	II	5	II	8	II	5	II	4	II	3	II	4	II	2	I
Check....	—	—	—	—	9	II	5	II	7	II	5	II	—	—	3	II	4	II	5	I

In the early experiments gelatin was used as the culture medium, but later this was replaced by agar, as the latter was found to serve the purpose equally well and, moreover, there is less possibility of its liquefaction. The following were the formulae used as given in abbreviated form in the first column of TABLE II: levulose, dextrin, glucose, maltose, lactose, inulin, and sucrose, in each case 2 per cent. of the carbohydrate with 12 per cent. gelatin; glucose (a), 5 per cent. glucose, gelatin 15 per cent. and one drop of 10 per cent. lactic acid; dung extract, fresh horse dung extracted with cold water and 15 per cent. gelatin; Raulin (a), Lendner's (1908) formula with substitution of glucose for sucrose; beef broth, 0.75 gm. Armour's beef extract, 50 gm. gelatin and 500 c.c. water; inorganic salts, 1.0 gm. KNO_3 , 0.5 gm. KH_2PO_4 ,

0.25 gm. $MgSO_4$, 0.5 gm. $CaCl_2$, 100 gm. water, and 12.0 gm. gelatin; check, 12 per cent. gelatin with distilled water.

In this experiment the cultures were made in test tubes and about 5 c.c. of the medium were used. The cultures were kept in the dark at room temperature (15–22 degrees C.). All cultures were made in duplicate, and in many cases, where there was a doubt in the mind of the writer, the experiment was repeated. The results are best obtained by consulting TABLE II, from which we see that levulose is the best medium in this series, followed by dextrin, glucose (acid), glucose, dung extract, Raulin's (acid) in the order named. Sucrose is the poorest, probably because many of the forms are unable to invert it.

TABLE III
HEIGHT AND GROWTH OF MUCORS WITH MISCELLANEOUS AGAR MEDIA

Media	Mucor No. 26		Mucor No. 34		Mucor No. 5		Mucor No. 24		Mucor No. 28		Mucor No. 6		Mucor No. 51	
	Ht.	G.	Ht.	G.	Ht.	G.	Ht.	G.	Ht.	G.	Ht.	G.	Ht.	G.
Rolled oats	70	IV	68	IV	42	IV	30	IV	40	IV	45	IV	10	IV
Glucose-asparagin agar	50	IV	27	IV	30	IV	18	IV	23	IV	24	IV	10	IV
Potato agar	65	III	55	IV	37	IV	32	IV	21	III	22	III	10	III
Corn meal	65	IV	60	III	35	III	20	III	30	III	25	III	5	III
Bread	40	III	60	III	10	III	25	III	25	III	15	III	10	III
Rice	50	IV	40	III	25	III	20	III	20	III	20	III	8	II
Glucose-nitrate agar	40	III	8	III	27	IV	13	III	17	III	19	III	13	III
Mannit-asparagin agar	25	II	9	III	22	III	15	III	11	III	6	II	10	III
Wheat-starch paste	50	III	25	II	25	III	20	III	20	II	20	III	10	II
Grapefruit	21	II	3	II	19	II	15	II	18	II	10	II	5	II
Sucrose-asparagin agar	38	II	5	I	14	II	20	II	7	II	5	II	9	II
Navy bean agar	27	II	33	II	13	II	20	III	9	I	8	II	5	I
Sucrose-nitrate agar	40	II	4	I	15	I	11	I	5	II	5	I	7	I
Mannit-nitrate agar	20	I	25	I	8	I	13	II	1	I	0	0	6	I
Apple agar	40	I	10	I	5	I	11	I	5	I	10	I	5	I
Prunes	1	I	1	I	10	II	1	I	1	I	—	I	1	I

In the next series of experiments various agar and complex media were used. See TABLE III. An explanation of the formulae of these media follows. Potato agar was made according to the method given by Thom (1905), and apple agar was prepared in the same way. For bean agar Thom's (1910) formula was used. For glucose-, mannit-, and sucrose-asparagin agar, and for glucose-, mannit-, and sucrose-nitrate agar, a combination of mineral salts (0.25 gm. $MgSO_4$, and 0.5 gm. KH_2PO_4) was used with 5.0 gm. of the carbohydrate, and 1.0 gm. of either

ammonium nitrate or asparagin. Rolled oats and wheat starch were both used with water in the proportion of 1 : 2 parts water by weight; corn meal was used with equal parts of water. Bread was used in the same manner as previously mentioned. Rice was used with three parts of water. Only the pulp and juice of the grapefruit were used. In the case of prunes, about one fourth of a prune was moistened with 5 c.c. of water. The results are given in TABLE III.

From this table we see that the best growth occurs on rolled oats, and that of the six best media, five are complex substances, while the sixth—glucose-asparagin agar—contains an available carbohydrate and an organic nitrogen compound. A comparison of the results obtained with glucose-asparagin agar and glucose-nitrate agar shows that the former is a more favorable medium. This is due to the form of the nitrogen offered the plant, and this nitrogen source is probably one of the important reasons why complex media are more suitable for these forms. Mannit with asparagin is better than sucrose with asparagin, but sucrose with nitrate is a better combination than mannit with nitrate. This is in accord with Jost's (1907) statement that the quality of the nitrogenous material has an influence on the nutritive value of any particular carbon compound. The growth on grapefruit was fair, while that on prunes was poor. This last result was, in all probability, due to the fact that the medium contained too high a percentage of sugar. This hypothesis is borne out by the fact that in practically all cases in which growth occurred, only a sterile mycelium developed. It should be mentioned in connection with the use of rice that, in order to determine whether there would be any difference in results with rice from different places, an experiment was set up with fifty-three numbers of mucors, using rice from different sources, purchased in Detroit and in Ann Arbor. The results showed no appreciable difference.

It seemed advisable, from the results obtained in the first two series of experiments, to select certain media and test them with a larger number of forms. Consequently a series of cultures was made with rice, bread, and grapefruit, including a large number of mucors. The height of the cultures is given in TABLE IV.

An interesting feature of the cultures on rice was the frequent

occurrence, on the surface of the medium around the edges of the culture, of a bright-colored line; this is pinkish to light orange yellow (Ridgway, 1912). Data on sixty-four numbers of *Mucor* show that thirty-four exhibited this color production, while twenty-eight numbers (Nos. 9, 10, 12, 24, 25, 26, 30, 34, 35, 38, 40, 41, 42, 44, 46, 48, 49, 50, 51, 54, 58, 59, 61, 62, 63, 68, 73, and 2) formed no color at the top of the substratum.

TABLE IV
HEIGHT OF MUCORS ON BREAD, RICE, AND GRAPEFRUIT¹

Species used	Rice	Bread	Grape-fruit	Species used	Rice	Bread	Grape-fruit
<i>Mucor</i> No. 1	15	15	12	<i>Mucor</i> No. 36	30	10	13
<i>Mucor</i> No. 2	2	2	0.5	<i>Mucor</i> No. 37	30	20	8
<i>Mucor</i> No. 3	20	8	11	<i>Mucor</i> No. 38	20	10	17
<i>Mucor</i> No. 4	20	30	17	<i>Mucor</i> No. 39	30	15	15
<i>Mucor</i> No. 5	25	15	19	<i>Mucor</i> No. 40	20	40	11
<i>Mucor</i> No. 6	20	15	10	<i>Mucor</i> No. 41	20	5	4
<i>Mucor</i> No. 7	30	20	12	<i>Mucor</i> No. 42	15	4	2
<i>Mucor</i> No. 9	35	8	13	<i>Mucor</i> No. 43	35	12	11
<i>Mucor</i> No. 10	10	25	14	<i>Mucor</i> No. 44	3	4	3
<i>Mucor</i> No. 11	13	10	13	<i>Mucor</i> No. 45	30	13	12
<i>Mucor</i> No. 12	20	6	10	<i>Mucor</i> No. 46	25	12	11
<i>Mucor</i> No. 13	10	—	10	<i>Mucor</i> No. 47	—	5	4
<i>Mucor</i> No. 14	30	20	13	<i>Mucor</i> No. 48	—	4	3
<i>Mucor</i> No. 15	15	7	8	<i>Mucor</i> No. 49	10	—	8
<i>Mucor</i> No. 16	15	10	15	<i>Mucor</i> No. 50	20	17	7
<i>Mucor</i> No. 18	30	12	15	<i>Mucor</i> No. 51	8	10	5
<i>Mucor</i> No. 19	35	10	10	<i>Mucor</i> No. 54	5	3	10
<i>Mucor</i> No. 20	20	8	12	<i>Mucor</i> No. 56	30	6	12
<i>Mucor</i> No. 21	30	35	11	<i>Mucor</i> No. 57	20	12	11
<i>Mucor</i> No. 22	35	10	13	<i>Mucor</i> No. 58	25	15	12
<i>Mucor</i> No. 23	10	—	9	<i>Mucor</i> No. 59	10	8	4
<i>Mucor</i> No. 24	30	25	15	<i>Mucor</i> No. 60	35	12	15
<i>Mucor</i> No. 25	25	10	7	<i>Mucor</i> No. 61	7	3	5
<i>Mucor</i> No. 26	50	40	21	<i>Mucor</i> No. 62	3	2	—
<i>Mucor</i> No. 28	25	25	18	<i>Mucor</i> No. 63	20	15	10
<i>Mucor</i> No. 29	30	22	12	<i>Mucor</i> No. 67	15	—	10
<i>Mucor</i> No. 30	15	9	12	<i>Mucor</i> No. 68	20	20	20
<i>Mucor</i> No. 31	20	20	13	<i>Mucor</i> No. 70	—	10	12
<i>Mucor</i> No. 32	25	11	15	<i>Mucor</i> No. 72	10	10	10
<i>Mucor</i> No. 33	25	15	15	<i>Mucor</i> No. 73	30	25	25
<i>Mucor</i> No. 34	40	60	3	<i>Mucor</i> No. 74	15	3	10
<i>Mucor</i> No. 35	25	12	17	<i>Mucor</i> No. 76	25	—	17

From the preceding experiments it has been shown that complex media are, on the whole, better for these plants than simple media, and as bread is a universally staple article easily obtained, as well as easy to work with, it has been used as a standard medium to grow these forms for taxonomic study.

A series of sixty-five numbers of *Mucor* (including all the species of *Mucor* collected with the exception of *Mucor botryoides*) was tested for their ability to ferment a dextrose, peptone solution (dextrose 10 per cent., peptone 0.1 per cent.) with positive results, except in the case of *Mucor Ramannianus*.

Because certain organisms have the ability to change tyrosin, by the production of an enzyme, into a dark-colored compound, often accompanied by the production of a brownish black precipitate, it was decided to use this organic compound with a series of mucors. For this experiment a solution of the following composition was employed: maltose 2 per cent., peptone 0.1 per cent., tyrosin 0.015 per cent. (1 gm. tyrosin to 6,400 c.c. of solution). The same mucors which were used in the preceding experiment were also employed for this series. The results may be given in the following brief manner. Four (Nos. 22, 36, 57, and 67) were discarded on account of bacterial contamination. In Nos. 4, 5, 6, and 72 there developed an apricot yellow (Ridgway) submerged mycelium, the color being due to yellow globules in the hyphae. The following showed a slight production of yellow color in the submerged hyphae: Nos. 1, 3, 7, 9, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 25, 28, 29, 31, 32, 33, 37, 38, 39, 42, 43, 56, 58, 60, 74, and 76. No color formation was found in Nos. 2, 10, 23, 24, 30, 34, 41, 44, 45, 46, 47, 48, 49, 50, 51, 54, 59, 61, 68, and 70. There was a marked coloration of the solution, with the formation of a dark brown precipitate, in Nos. 26 (*Mucor griseosporus*) and 73 (*Mucor coprophilus*), the color of the solution in each case being dark reddish brown. In Nos. 34, 44, 51, and 61, the solution was colored pale brown, and a dark brownish black precipitate was formed. In Nos. 40 and 63 (both *Glomerula repens*) there was a brownish tinge to the solution, and the aerial growth was distinctive in that it was pinkish buff (Ridgway).

[To be concluded.]

A critical study of certain species of *Mucor*

ALFRED H. W. POVAH

(WITH PLATES 17-20)

[Concluded from page 259]

V. TAXONOMIC

In the preceding experimental part of this work it has been shown that the species of *Mucor*, with but few exceptions, are rather plastic organisms, varying considerably with the external conditions, particularly the substratum. This fact, together with the lack of emphasis as to its importance, especially in questions of taxonomy, has led to a great deal of confusion and often to the description of a single species under several names. In view of this fact it appeared most desirable to attempt a standardization of the cultural requirements and to undertake a detailed study of as many forms as possible under such conditions. Early in the work it was seen that it would be necessary to limit the field of study, and as the genus *Mucor* is composed of so many species which offered difficulty, it was decided to include only this genus in the detailed study. In the aggregate, over one hundred collections (numbering those from which no mucors were isolated) have been made during the last three years. A glance at TABLE I will show the result: eighty-four collections gave mucors, twenty-eight from dung, twenty-two from decaying plant or animal substances, twenty-three from soil, etc. Fourteen genera of the Mucorales, including thirty-seven species, were isolated: *Mucor*, nineteen species; *Absidia*, two species; *Rhizopus*, two species; *Sporodinia*, one species; *Phycomyces*, one species; *Circinella*, one species; *Glomerula*, one species; *Zygorhynchus*, one species; *Heliocostylum*, one species; *Thamnidium*, one species; *Pilobolus*, three species; *Chaetocladium*, one species; *Cunninghamella*, one species; and *Syncephalis*, two species.

It will be observed (TABLE I) that sixty-six collections of *Mucor* were obtained, which are referred to nineteen species. Of these, six species are undescribed, viz.: *Mucor abundans*, *M.*

varians, *M. aromaticus*, *M. griseosporus*, *M. coprophilus*, and *M. griseo-lilacinus*.

As has been mentioned before, it was decided to use bread as a standard medium for the comparative study of the species of *Mucor*. A convenient and, at the same time, uniform style of culture was a further desideratum. The tall lipless beakers described in the method of making herbarium preparations proved unsuitable in this case, by reason of their large size, and the impossibility of opening them after they had stood for some time without contaminating the culture. This was doubtless due to the fact that the cotton used to make the (Petri dish) cover tight served as a collector of spore-containing dust. After several arrangements, the following method was evolved, and this has proved successful and easy of manipulation. Two glass capsules, each containing about 1 c.c. of bread (fresh bread, slightly moistened, or dried bread with sufficient water added to form a paste after autoclaving), were placed side by side in a 125 mm. crystallizing dish. This was covered first with a thin layer of cotton batting, and then with a circular glass plate about 12.5 cm. in diameter. These preparations were autoclaved three or four hours at fifteen pounds pressure. All of the descriptions and figures, unless otherwise specified, were made from cultures prepared according to the above-described method. The height in each case was checked by comparison with herbarium cultures in the tall beakers.

The author assumes that anyone attempting to identify a mucor has found some difficulty with the already existing keys, in that it is necessary first of all to determine whether or not the sporangiophores are branched or simple, and if the former, whether racemously or cymosely branched. To facilitate matters, consideration will first be given to the question of simple and branched sporangiophores. Lendner gives as a parenthetical expression after his unbranched group "exceptionally, when the conditions of nutrition are unfavorable, branches are formed; they are cases of anomaly." This immediately causes trouble, because if branching is found in a species it must be determined whether it is anomalous or not. To give a concrete example, Wehmer (1903) described a mucor under the name *Mucor hiemalis* as "mostly unbranched (seldom with lateral branches)," and this has been

placed by Lendner under the unbranched group. Hagem (1908) says that after a study of Wehmer's species he believes that *Mucor hiemalis* has simple sporangiophores only in young cultures, later becoming profusely branched. *M. Mucedo* L., also, has always been classed as a simple form, yet in most descriptions branching is given as occurring rarely. It seems better, therefore, not to follow the traditional separation into branched and unbranched forms. The question of kind or type of branching is even more difficult to determine as both types often occur in the same species (*M. saturninus*). Moreover, different students of the group place the same species under different types of branching. Examples of this disagreement are shown in the case of *M. sphaerosporus*, *M. griseo-cyanus*, and *M. silvaticus*, all of which were described by Hagem. He placed the first two in the *Racemo-Mucor* group and the third in the *Cymo-Mucor* group. Lendner changes all three, placing the first two in the cymose, and the third in the racemose group. From this it is manifest that branching is a poor means of separation of species in a key. For these and other reasons to be given later, the writer has discarded this character in the preparation of the following key which contains the species studied from uniform, standard bread cultures.

KEY TO SPECIES STUDIED

- | | |
|--|--|
| 1. Turf 5 cm. tall or over | 1. <i>M. proliferus</i> Schostak. |
| 1. Turf 0.5-5 cm. tall | 2 |
| 1. Turf less than 0.5 cm. tall | 16 |
| 2. Spores globose, subglobose to suboval | 3 |
| 2. Spores not globose to suboval | 9 |
| 3. Turf some shade of gray | 4 |
| 3. Turf dark brown | 8 |
| 4. Turf loose, soon collapsing | 2. <i>M. christianiensis</i> Hagem. |
| 4. Turf dense, remaining erect | 5 |
| 5. Spores large, shining, 8-13 μ | 3. <i>M. lamprosporus</i> Lendner. |
| 5. Spores small, not exceeding 6 μ | 6 |
| 6. Columella subglobose to pyriform | 4. <i>M. abundans</i> sp. nov. |
| 6. Columella globose to oval | 7 |
| 7. Sporangia brownish; circinate sporangiophores
near substratum | 5. <i>M. circinelloides</i> Van Tiegh. |
| 7. Sporangia grayish; circinations not present | 6. <i>M. corticolus</i> Hagem. |
| 8. Columella spinescent; chlamydospores rarely in
sporangiophores | 7. <i>M. plumbeus</i> Bonorden. |
| 8. Columella smooth; chlamydospores usually in
sporangiophores | 8. <i>M. sphaerosporus</i> Hagem. |

9. Spores elliptical or cylindrical 10
 9. Spores not elliptical or cylindrical 12
 10. Culture aromatic; turf ochraceous 9. *M. aromaticus* sp. nov.
 10. Culture not aromatic; turf gray 11
 11. Columella pyriform to panduriform; spores 8-12
 $\times 5-6 \mu$ 10. *M. griseosporus* sp. nov.
 11. Columella cylindrical to pyriform; spores 9-16
 $\times 5-8 \mu$ 11. *M. coprophilus* sp. nov.
 12. Turf ivory yellow to olive buff (Ridgway) 12. *M. varians* sp. nov.
 12. Turf some shade of gray 13
 13. Turf loose; columella oval to pyriform 13. *M. saturninus* Hagem.
 13. Turf dense; columella not oval to pyriform 14
 14. Spores not uniform, subreniform, subfusiform 14. *M. hiemalis* Wehmer.
 14. Spores uniform oval 15
 15. Sporangia deep bluish-gray; circinate sporangio-
 phores near substratum 15. *M. griseo-cyanus* Hagem.
 15. Sporangia dark greenish-gray; circinations not
 present 16. *M. griseo-lilacinus* sp. nov.
 16. Turf red; columella smooth 17. *M. Ramannianus* Moeller.
 16. Turf brown; columella spinescent 18. *M. spinescens* Lendner.

DESCRIPTIONS OF SPECIES

1. MUCOR PROLIFERUS Schostak. Ber. Deutsch. Bot. Ges. 14: 260. pl. 18, f. 1-14. 1896

Forming on bread a loose, erect, smoke gray (Ridgway) turf, tinged drab, 2-6 cm. tall; *sporangiophores* septate, 23-82 μ in diameter, simple or profusely branched, with long and then usually simple, or short, simple or ramified branches; *sporangia* large (terminal) or small (lateral), 210-349 μ and 31-74 μ in diameter, respectively, encrusted with crystals, small lateral sporangia often deciduous; *sporangium wall* persistent or rupturing (in the case of the small sporangia), or deliquescent (large terminal sporangia), leaving a basal membrane; *columella* free, cylindrical to pyriform (approaching panduriform), 125-150 $\times$ 58-90 μ (extremes 70-266 $\times$ 43-174 μ), tinged brownish; *spores* elliptical, 8-10 $\times$ 4-6 μ in diameter (extremes 6-16 $\times$ 4-8 μ), hyaline; *zygospores* globose or somewhat flattened at the ends (diameter with axis through suspensors 17-31 μ less than diameter perpendicular to it), 154-168 $\times$ 127-137 μ (extremes 116-182 $\times$ 99-154 μ), dark brown, becoming brownish black at maturity, young zygospores with small, round warts, which become large and irregular in mature zygospores, suspensors subequal, heterothallic (single spore cultures produce no zygospores). [PLATE 19, FIGS. 6-10.]

This interesting species was collected only once, on dung. The zygospores, before unknown, were found in the original culture

and in cultures made by gross transfers to bread. In order to separate this mucor from other fungi present, single spore cultures were made and only one strain was isolated. The collection dates from the early part of the work (1913); consequently no effort was made to isolate both strains. No. 34.

This mucor exhibits a great difference in height according to the substratum. A maximum height of 68 mm. was obtained on rolled oats; while the following data give some idea of the range of variation: bread and cornmeal, 60 mm.; potato agar, 55 mm.; rice, 40 mm. with no color production; bean agar, 33 mm. On grapefruit it does not exceed 3 mm. It was found to ferment dextrose and to oxidize tyrosin solution.

2. MUCOR CHRISTIANIENSIS Hagem, Ann. Mycol. 8: 268. f. 2-3.
1910

Forming on bread a loose, smoke gray turf (Ridgway), with drab tinge, 1-3.5 cm. tall, soon collapsing; *sporangiophores* 6-16 μ in diameter, sparsely ramified with a few long or short branches ending in a sporangium and with a septum above point of insertion of branch; *sporangia* globose, 50-80 μ (extremes 43-121 μ) in diameter, pale brown, transparent with the spores showing through; *sporangium wall* rupturing, leaving a usually large, or small basal membrane; *columella* free or slightly adnate, oval to pyriform, 20-82 $\times$ 16-62 μ , pale brown; *spores* subglobose to suboval, 6-10 $\times$ 5-8 μ or 5-9 μ in diameter (extremes 4-12 $\times$ 3-10 μ); *chlamydospores* numerous in the sporangiophores, oval or barrel-shaped when young, globose at maturity, 16-23 μ in diameter; *zygospores* not found (presumably heterothallic).

This species was collected four times; twice from soil in potting bench and bed of different greenhouses, once on fallen leaf (by Mr. E. Levin), and once on Brazil nut. Nos. 48, 54, 59, and 77. It is related, as Hagem (1910) has pointed out, to *Mucor racemosus* Fresen., but differs principally in the fact that the chlamydospores become spherical at maturity, while in *M. racemosus* they remain barrel-shaped.

Mucor christianiensis varies but little in height on the different substrata used: on rice it is 5-10 mm. high; on bread, 4-8 mm.; and on grapefruit, 3-10 mm. The species was found to ferment dextrose but did not oxidize tyrosin. Moreover, it does not form any yellow color on rice.

3. *MUCOR LAMPROSPORUS* Lendner, Bull. Herb. Boissier II. 8: 78. 1908; Les Mucorinées de la Suisse, 92. Berne, 1908

Forming on bread an erect, dense, pale smoke gray (Ridgway) turf, 1.5–3 cm. tall; *sporangiophores* 10–23 μ in diameter, ramifying with a few long branches, or with very short, circinate branches, ending in a sporangium; *sporangia* globose, terminal 62–82 μ in diameter, lateral 33–43 μ ; *sporangium wall* of large sporangia rapidly deliquescent (glycerine mount necessary to obtain sporangial measurements), of small sporangia persistent or dissolving, leaving a slight basal membrane; *columella* globose to oval, free, 16–51 $\times$ 18–43 μ ; *spores* globose, shining, large, 8–13 μ in diameter; *zygospores* not found (presumably heterothallic).

A single collection of this species, easily recognized by the large shining spores, was obtained from an oak root, found by Mr. H. Andrews, brought into the Cryptogamic Laboratory and placed in a moist chamber for study of mycorrhiza. No. 35. It is interesting to note, in this connection, that the closely-related species *Mucor sphaerosporus* Hagem was obtained from mycorrhiza of *Pinus montana* by Professor Gran in Norway.

On rice this species grows 25 mm. high and on grapefruit 17 mm. It ferments dextrose, but does not oxidize tyrosin.

4. *Mucor abundans* sp. nov.

Forming on bread a dense, erect, smoke gray turf (Ridgway), tinged drab, 1.5–3.5 cm. tall; *sporangiophores* 8–23 μ in diameter, at first simple, later with one to three lateral branches which are in turn branched once or twice (exceptionally five times), with branches always terminating in a sporangium, and with a septum above point of insertion of branch; *sporangia* globose or subglobose, smooth or incrustated with very delicate crystals, 56–78 μ in diameter (extremes 39–98 μ), at first yellowish, becoming dark gray with a greenish tinge at maturity; *sporangium wall* deliquescent, leaving a basal membrane; *columella* subglobose to pyriform, free or slightly adnate, 31–40 $\times$ 25–35 μ (extremes 21–66 $\times$ 20–55 μ), hyaline or tinged gray; *spores* variable, globose to short elliptical, 3–5 μ in diameter or 4–5.5 $\times$ 3–4.5 μ (a few 8 $\times$ 6 μ); *chlamydo-spores* and yellowish globules in submerged mycelium; *zygospores* not found (presumably heterothallic). [PLATE 17, FIGS. 1–6.]

This species was found to be very common, no less than eleven collections having been made from the following sources: three times from horse dung, twice from sandy tilled soil, three times

from dung (presumably squirrel), once from decaying tomato, rabbit dung, and dog dung, respectively. Nos. 7, 9, 14, 19, 22, 25, 28, 31, 32, 33, and 60. Nos. 14 and 22 were collected by Messrs. K. Duncan and E. B. Mains, respectively.

Mucor abundans is characterized by the oval to pyriform columella, the variable—globose to short-elliptical—spores, and the color of the turf (smoke gray tinged drab). It is related to *Mucor griseo-lilacinus*, but differs from it in the color of the turf, the oval to pyriform columella, the variable—globose to short elliptical—spores, and the absence of the lilac tinge in the columella and hyphae. It is also related to *M. hiemalis* (sense of Hagem), from which it differs in the shape of the columella and in the shape and size of the spores.

Mucor abundans grows 40 mm. tall on rolled oats, 30 mm. tall on corn meal, 25–35 mm. tall on rice, with or without the formation of buff to yellow line around edges of surface of rice, and 9–18 mm. tall on grapefruit. It ferments dextrose, but does not oxidize tyrosin.

5. MUCOR CIRCINELLOIDES Van Tiegh. Ann. Sci. Nat. Bot. VI.

1: 94. 1875

Forming on bread a dense, pale smoke gray (Ridgway) turf, 1–3 cm. tall; *sporangiophores* 8–16 μ in diameter, tall and short, tall forming a turf 2–3 cm. tall, and short attaining only 1–2 mm. in height, *tall sporangiophores* with long or short branches, *short sporangiophores* more profusely branched with short and often circinate branches, always terminating in a sporangium and with a septum above the point of insertion of branch; *sporangia* globose, of tall sporangiophores, 50–70 μ in diameter (extremes 43–80 μ), of dwarf sporangiophores, 14–35 μ in diameter, at first yellowish, becoming brownish gray at maturity; *sporangium wall* deliquescent in sporangia borne on tall sporangiophores, rupturing or persistent in sporangia of dwarf circinate sporangiophores, leaving a basal membrane; *columella* free, globose to oval, 31–43 $\times$ 31–39 μ (extremes 20–51 $\times$ 18–43 μ), tinged grayish; *spores* uniform, subglobose to oval, 3–5 $\times$ 3–4 μ or 3–5 μ in diameter (extremes 8 $\times$ 6–8 μ in diameter); *chlamydospores* and oidia in and on substratum, chlamydospores 20 $\times$ 12 μ ; *zygospores* not found (species heterothallic).

This species is characterized by the tall and short (often circinate) sporangiophores, the subglobose to oval columella, and

the uniform—subglobose to oval—spores, measuring $3.5 \times 3.4 \mu$ or 3.5μ in diameter. It is related to *M. griseo-cyanus* Hagem, from which it differs in the color of the turf, color of the sporangia, and the spores. It is also related to *M. abundans* but differs from it in the color of the turf, circinate ramifications, shape of columella, and the spores. In *Mucor circinelloides* the spores are uniform, subglobose to oval, while in *M. abundans* they are variable, globose to short elliptical, also slightly larger.

Mucor circinelloides was collected six times from soil, four times from tilled soil, once from greenhouse (potting bench), and once from soil in cold frame. Nos. 38, 39, 42, 43, 45, and 56.

This species is 15–35 mm. tall on rice, without color production or with a pale pinkish (or ochraceous) buff (Ridgway) line around the edges of the top of the substratum. On grapefruit it is 2–17 mm. tall. It ferments dextrose but does not oxidize tyrosin solution.

6. *MUCOR CORTICOLUS* Hagem, Ann. Mycol. 8: 277. f. 8. 1910

Forming on bread a dense, pale smoke gray to smoke gray (Ridgway) turf, 0.5–2 cm. tall; *sporangiophores* 6–16 μ in diameter, profusely branched with long often ramified branches, terminating in a sporangium and with a septum above point of insertion of branch; *sporangia* encrusted with delicate crystals, globose, 51–94 μ in diameter, dark gray; *sporangium wall* deliquescent, leaving a large or small basal membrane; *columella* free or slightly adnate, mostly oval (a few subglobose), $31\text{--}62 \times 27\text{--}32 \mu$ (extremes $16\text{--}62 \times 14\text{--}51 \mu$), tinged gray; *spores* subglobose to suboval, $3.5\text{--}5 \times 3\text{--}3.5 \mu$ or $4\text{--}5 \mu$ in diameter (extremes $8 \times 6 \mu$ or $6\text{--}7 \mu$ in diameter); *zygospores* not found (species presumably heterothallic).

A single isolation of this species was obtained from soil (just beneath the surface) in a corn field. No. 57. This species, which is related to *M. silvaticus* Hagem, is characterized by the fact that the lateral branches are usually shorter than the long, often bending main axis; by the usually oval columella; and by the different-shaped and often larger spores.

Mucor corticolus forms a drab gray (Ridgway) turf, 2 cm. tall on rice with the production of a pinkish buff line around the edges of the surface of the rice. It ferments dextrose but does not oxidize tyrosin.

7. MUCOR PLUMBEUS Bonorden (sense of Lendner), Abh. Naturf. Ges. Halle 8: 109. *pl.* 1, *f.* 20. 1864

Forming on bread a dense, fuscous (Ridgway) turf, 0.1–1 cm. tall; *sporangiophores* 10–16 μ in diameter, profusely branched with branches ending in a sporangium and with a septum above point of insertion of branch, also septate at irregular intervals in the sporangiophores; *sporangia* globose, 60–80 μ in diameter (extremes 35–117 μ), brownish black, encrusted with crystals or smooth; *sporangium wall* deliquescent, leaving a basal membrane; *columella* free, oval, pyriform, elongated, or conical, smooth or furnished with one to twelve spines at the apex, 30–60 $\times$ 16–32 μ (extremes 16–74 $\times$ 12–59 μ), dark brown; *spores* globose, 6–9 μ in diameter (extremes 5–13 μ), also a few elliptical and irregular-shaped spores, 23 $\times$ 18, 16 $\times$ 12 μ , dark brown, punctate; *zygospores* not found (species heterothallic).

This species was obtained four times: twice as contamination in cultures; from *Sphagnum* with germinating seeds; and from a decayed Brazil nut. Nos. 47, 51, 61, and 78. The species is quite variable, as a comparison of the descriptions given by Fischer and Lendner will show. Moreover, there are transitional forms between it and the closely related species, *M. spinescens* Lendner. On potato agar, rolled oats, and bread, *M. plumbeus* reaches a height of 10 mm., on rice, 7–8 mm., on cornmeal, 5 mm. and on grapefruit, 4–5 mm. There is no color production on rice. It ferments dextrose and oxidizes tyrosin, but more slowly than *M. coprophilus* and *M. griseosporus*.

8. MUCOR SPHAEROSPORUS Hagem, Vid.-Selsk. Skr. M.-N. Kl. Christiania 1907⁷: 22. *f.* 4. 1908

Forming on bread a dense, 2 mm. high, and a sparse, 1 cm. high, hair brown (Ridgway) turf; *sporangiophores* 6–18 μ in diameter, typically branched, with one long branch (in turn profusely ramified), or several short, simple branches, in either case with branches terminating in a sporangium and with a septum above the point of insertion of a branch; *sporangia* globose, 78–86 μ in diameter (extremes 59–98 μ), with spores shining through, brown; *sporangium wall* deliquescent, leaving a basal membrane; *columella* free or slightly adnate, subglobose to pyriform, 39–59 $\times$ 35–47 μ (extremes 23–70 $\times$ 21–59 μ), tinged brown; *spores* uniformly globose, 5–8 μ in diameter (extremes 4–10 μ), yellowish; *chlamydospores* in sporangiophores, globular, with central oil globule; *zygospores* not found (presumably heterothallic).

This species was obtained twice, from decayed leaf and as a contamination in a culture. Both of these the writer received from Mr. E. Levin. Nos. 49 and 50. It belongs to the *M. racemosus* group of mucors but can readily be distinguished from the above-mentioned species by the color of the turf, which is nearest to that of *M. plumbeus*, although it is slightly lighter. The branching in *M. sphaerosporus* is much more profuse than in *M. racemosus*; and while the spores are very similar in the two species, the chlamydospores are different. In *M. sphaerosporus* they are globular and have a central oil globule.

This species forms a hair brown (Ridgway) turf, 1-2 cm. tall on rice, without any yellowish coloration near surface of substratum; on grapefruit a 7-8 mm. tall, gray turf is produced. Dextrose is fermented but tyrosin is not oxidized by this species.

9. *Mucor aromaticus* sp. nov.

Forming on bread a loose, yellow ochre to ochraceous orange (Ridgway) turf, 2-3 cm. tall; *sporangiophores* 20-50 μ in diameter, typically unbranched or with one to three lateral branches always terminating in a sporangium; *sporangia* globose, 100-160 μ in diameter, encrusted with small crystals, more or less transparent, showing the spores within; *sporangium wall* deliquescent, without or with basal membrane; *columella* free, subglobose to oval, approaching pyriform, 51-121 $\times$ 43-105 μ , with or without protoplasmic contents, hyaline; *spores* uniform elliptical, 18-20 $\times$ 10 μ (extremes 15-35 $\times$ 7-14 μ), a few oval, also approaching spherical; *culture* strongly aromatic, with odor somewhat like camphor and celluloid; *zygospores* not found (species presumably heterothallic). [PLATE 17, FIGS. 7-11.]

This species is characterized by its ochraceous color and its odor. Its origin was dung (squirrel?), and the writer is indebted to Professor J. B. Pollock, who collected it. No. 24.

Mucor aromaticus varies with the substratum as may be seen from the following data. On potato agar it grows 32 mm. tall; on bean agar, 20 mm.; on apple agar, 11 mm.; on rolled oats, 30 mm.; on cornmeal, 20 mm.; on starch paste, 20 mm.; and on rice, 20-30 mm. (often coloring the whole substratum yellow). It ferments dextrose (slight amount of alcohol found on second distillation), but does not oxidize tyrosin. Cultures on the following substrata were strongly aromatic: rolled oats, cornmeal, beef

gelatin, potato agar, dextrin gelatin, and rice. On starch paste and apple agar, however, the odor was slight.

10. **Mucor griseosporus** sp. nov.

Forming on bread a loose, erect, light grayish olive (Ridgway) turf, tinged brown, 3-4 cm. tall; *sporangiophores* with brownish membrane, 20-70 μ in diameter, typically unbranched, or with one or two short lateral branches terminating in small sporangia, becoming septate in old cultures; *sporangia* globose, terminal 244-302 μ in diameter, encrusted with crystals, lateral up to 98 μ in diameter, at first yellowish becoming dark gray at maturity; *sporangium wall* deliquescent (except in small sporangia) leaving a basal membrane; *columella* free, pyriform, pyriform broadened at the base, or panduriform, 115-242 $\times$ 88-165 μ usually with yellowish to pale orange contents; *spores* uniform, elliptical 8-12 $\times$ 5-6 μ (extremes 8-15 $\times$ 5-8 μ), clear gray, in mass almost black, agglutinate; *zygospores* not found (presumably heterothallic). [PLATE 18, FIGS. 1-5.]

This species is characterized by its simple or slightly branched, septate, sporangiophores; its pyriform columella; and gray, uniformly elliptical spores. It is related to *M. piriformis* Fischer, but differs from it in the fact that the lateral branches terminate in sporangia; in having septate sporangiophores; basal membrane present; and slightly larger, and clear gray spores. Collected a single time on dung. No. 26.

M. griseosporus grows as follows: on rolled oats, 70 mm. tall; on potato agar and cornmeal, 65 mm. tall; on starch paste and rice, 50 mm.; on bread and apple agar, 40 mm.; on bean agar, 27 mm.; and on grapefruit, 21 mm. On rice there is no color production. It ferments dextrose to a slight extent, and oxidizes tyrosin.

11. **Mucor coprophilus** sp. nov.

Forming on bread a loose, light grayish olive (Ridgway) turf, 2-2.5 cm. tall; *sporangiophores* brown, 27-46 μ in diameter, ramifying with long branches, or shorter, simple or ramified, more slender branches (terminating in small often deciduous sporangia 20-62 μ in diameter, with rupturing membrane); *sporangia* (large terminal) globose, encrusted with crystals, 185-235 μ in diameter, whitish at first, becoming almost black at maturity; *sporangium wall* readily deliquescent (except in the case of sporangia on dwarf sporangiophores), leaving a small basal membrane; *columella* free,

cylindrical to pyriform, $110-160 \times 70-113 \mu$, brownish, sometimes with orange contents; *spores* narrowly elliptical in larger sporangia, $13-16 \times 5-6 \mu$, broadly elliptical in smaller sporangia, $9-12 \times 7-8 \mu$, grayish; *chlamydospores* rarely in sporangiophores; *zygosporos* not found (presumably heterothallic). [PLATE 19, FIGS. 1-5.]

This species is characterized by its varied habit of branching; its small, lateral, often deciduous sporangia, recalling *Mucor lamprosporus*; its cylindrical to pyriform columella; and its variable spores, narrowly elliptical and broadly elliptical in the larger and smaller sporangia respectively. It is related to *Mucor griseosporus*, from which it differs in its slightly lighter colored and shorter turf; more slender and more profusely branched sporangiophores; cylindrical to pyriform columella; and its variable (broadly to narrowly elliptical), larger, non-agglutinate spores. A single collection was obtained of this characteristic species from rabbit dung. No. 73. Ellis & Everhart's North American Fungi 972 is certainly not *Mucor Mucedo* (sporangia and spores too large), and probably ought to be referred to *M. coprophilus*.

This species forms a 30 mm. tall, Saccardo's olive (Ridgway) turf on rice and a 25 mm. tall, brownish gray turf on grapefruit. It produces no color on rice but oxidizes tyrosin and ferments dextrose to a slight extent.

12. *Mucor varians* sp. nov.

Forming on bread a dense, ivory yellow to olive buff (Ridgway) turf, 1-3.5 cm. tall; *sporangiophores* $8-20 \mu$ in diameter, either little or profusely branched, much coiled, twisted or intertwined, forming a dense, tough, cottony turf, with proliferations of hyphae and columellae often present; *sporangia* globose or subglobose, smooth, $60-80 \mu$ in diameter (extremes $43-116 \mu$), at first yellowish or pale orange, becoming very dark gray, tinged green, at maturity; *sporangium* wall deliquescent, leaving a basal membrane; *columella* free or slightly adnate, very variable in shape, subglobose, hemispherical, flattened hemispherical, oval, cylindrical, elliptical, pyriform, panduriform, cylindro-conical, subconical and conical, large columellae hemispherical to conical, small columellae cylindrical to pyriform and panduriform, $25-50 \times 20-45 \mu$ (extremes $18-70 \times 12-59 \mu$), membrane tinged gray, with or without orange contents; *spores* not uniform, oval to sub-elliptical (few spherical), $4-6 \times 3-4 \mu$ (extremes $4-14 \times 3-8 \mu$), $4-8 \mu$ in diameter, bizarre spores not rare, reniform, cruciform,

etc.; *zygospores* not found (presumably heterothallic). [PLATE 20, FIGS. 1-6.]

This species was isolated from soil (in hardwoods and tilled) four times; also from stable bedding and manure; from the stem of a decaying apple; and from *Calvatia* sp. (the last-mentioned collected by Dr. E. B. Mains). Nos. 18, 21, 29, 36, 37, 46, and 58.

Mucor varians is characterized by the color of its turf, chamois to deep olive buff (Ridgway) in dried herbarium specimens; by the extremely variable shape of the columella; by its dissimilar spores; and by its habit of growth, i. e., the peculiar intertwining, coiling, and proliferation of the hyphae. This species resembles *Mucor Jansseni* Lend. in the shape of the columella.

Mucor varians forms a light grayish olive to cartridge buff (Ridgway) turf, 25-30 mm. tall on rice, sometimes with the yellowish line at the edge of the surface of the medium. On grapefruit a gray or yellowish gray turf is formed, 8-15 mm. tall (sometimes with a bright orange line around the edge of the surface of the medium). It ferments dextrose but does not oxidize tyrosin.

13. MUCOR SATURNINUS Hagem, Ann. Mycol. 8: 265. f. 1. 1910

Forming on bread a loose, gull gray (Ridgway) turf, 2-2.5 cm. tall; *sporangiophores* of two kinds, tall and short, the former composing the turf, the latter forming patches of dark gray felt (less than 1 mm. thick) on the substratum, *tall sporangiophores* 12-35 μ in diameter, typically unbranched (sometimes with a single short branch ending in a sporangium), *short sporangiophores* simple or branched; *sporangia* globose, 57-156 μ in diameter, at first yellowish, becoming almost black at maturity, finely incrustated with crystals; *sporangium wall* dark gray, deliquescent (in sporangia of tall sporangiophores), rupturing (or persistent in sporangia of short sporangiophores), leaving a large or small basal membrane; *columella* free, tinged grayish, oval to pyriform, 34-107 $\times$ 39-80 μ , with or without pale orange contents; *spores* uniformly oval, variable in size, 6-8 $\times$ 4-6 μ (extremes 4-12 $\times$ 3-7 μ), pale gray in mass; *zygospores* not found (presumably heterothallic).

This species was found on horse dung and on decaying *Collybia dryophila* Bull. Nos. 10 and 68.

Mucor saturninus is characterized by the varying height of the sporangiophores, by the shape of the columella, and by the uniformly oval spores. The color of the turf is also characteristic.

This species forms a 14–20 mm. tall, gray turf on grapefruit and on rice a 10–20 mm. tall, pale smoke gray to smoke gray (Ridgway) turf. It ferments dextrose but does not oxidize tyrosin.

14. *MUCOR HIEMALIS* Wehmer, Ann. Mycol. 1: 37. f. 1–9. 1903

Forming on bread a dense, grayish white (Ridgway) turf tinged tilleul buff, 1–3 cm. tall; *sporangiophores* 16–20 μ in diameter, at first simple or, more often, once or twice (exceptionally up to six times) branched, with a septum immediately above point of insertion of branches, all of which terminate in a sporangium; *sporangia* globose, 60–75 μ in diameter (extremes 30–100 μ), at first yellowish becoming dark gray with a greenish tinge at maturity; *sporangium wall* deliquescent, leaving a basal membrane; *columella* free, globose to subglobose, 30–50 μ in diameter (extremes 20–55 μ), hyaline; *spores* variable in shape and size, subfusiform, subreniform, narrowly oval, subelliptical, 4–8 $\times$ 2–4 μ (a few 8–9 $\times$ 4–6 μ), hyaline; *zygospores* not found (species heterothallic). [PLATE 20, FIGS. 7–10.]

This species was isolated from various types of soil, from several kinds of dung, and from decaying mushroom. Nos. 4, 5, 6, 13, 72, and 74.

This agrees with Wehmer's description in general although the sporangia and columella are slightly larger, and branching is frequent. Both of these differences may be due to the influence of the substratum, as Wehmer has pointed out the variability of this species. The spores are characteristically variable, reniform being a common shape.

Mucor hiemalis exhibits the following cultural characteristics: on rice it forms a slightly yellowish, gray turf, 10–25 mm. tall (with a pinkish buff to orange buff line at margin of the upper surface of the substratum); on rolled oats the height is 42–45 mm.; on cornmeal, 25–35 mm.; on starch paste, 20–25 mm.; and on grapefruit, 10–19 mm. Dextrose is fermented to some extent but tyrosin is not oxidized. In the maltose-peptone-tyrosin solution an apricot yellow (Ridgway) submerged mycelium is formed.

15. *MUCOR GRISEO-CYANUS* Hagem, Vid.-Selsk. Skr. M.-N.

Kl. Christiania 1907: 28. f. 9. 1908

Forming on bread a dense, mouse gray to light mouse gray (Ridgway) turf, 0.5–1.5 cm. tall; *sporangiophores* 8–18 μ in

diameter, tall and short, tall forming the turf, and short remaining only 1–2 mm. in height, *tall sporangiophores* with long (more or less) straight branches, *short sporangiophores* with short (sporangia sometimes appearing almost sessile), usually circinate branches, always with septum immediately above point of insertion of branch; *sporangia* globose, 60–80 μ in diameter (extremes 39–98 μ), encrusted with tiny crystals, at first pale yellowish, becoming deep bluish gray at maturity; *sporangium wall* deliquescent (in sporangia of tall sporangiophores), rupturing (or persistent in sporangia of short sporangiophores), leaving a large or small basal membrane; *columella* globose to oboval, free or slightly adnate, 33–39 $\times$ 31–33 μ (extremes 20–58 $\times$ 17–47 μ); *spores* uniformly oval, gray in mass, 5–6 $\times$ 4–5 μ (a few 8 $\times$ 5 μ); *chlamydospores* forming creamy patches (sometimes to the exclusion of sporangio-phore production) on surface of substratum, globose, oval to ventricose fusiform, terminal or intercalary, singly or in bead-like chains, 16 μ in diameter or 20 $\times$ 10–12 μ ; *zygospores* not found (species presumably heterothallic).

This species was collected twice: once, by the writer, on dung (squirrel?), and once on old bones in the Zoological Laboratory of the University of Michigan by Miss C. Reeves. Nos. 12 and 30.

Mucor griseo-cyanus forms a gray turf 15–20 mm. tall on rice and a 10–12 mm. gray turf on grapefruit. It has the ability to ferment dextrose but can not oxidize tyrosin.

16. *Mucor griseo-lilacinus* sp. nov.

Forming on bread a dense, mouse gray (Ridgway) turf becoming in age tinged with drab, 1–1.5 cm. tall; *sporangiophores* 8–20 μ in diameter, at first simple, later with one or two lateral branches which are in turn ramified once to three times (exceptionally eleven times) with branches always terminating in a sporangium, and with a septum above point of insertion of branch; *sporangia* globose or subglobose, 60–80 μ in diameter (extremes 40–100 μ), at first yellowish, becoming dark gray with greenish tinge at maturity; *sporangium wall* deliquescent, leaving a basal membrane; *columella* free or slightly adnate, globose to subglobose, 27–43 μ in diameter (extremes 12–67 μ), tinged lilac gray; *spores* uniform, oval, 4–6 $\times$ 3–4 μ (a few large, 8 $\times$ 6, 10 $\times$ 5 μ), pale gray in mass; *chlamydospores* and *oidia* present in hyphae, chlamydospores globular to barrel-shaped, 10–30 μ in diameter; *hyphae* (especially those near the substratum) with a lilac tinged membrane and often with orange yellow contents; *zygospores* not found (species presumably heterothallic). [PLATE 18, FIGS. 6–10.]

This mucor was obtained from the following sources: stem of decayed grape, decaying pine needle, *Psalliota campestris* (L.) Fr., sheep, rodent, and horse dung. Nos. 1, 3, 11, 15, 16, 20, and 23.

The species is characterized by its uniform, oval spores, its globose to subglobose, slightly adnate, columella and the lilac tint in the columellae and hyphae. This color is sometimes darker (pale purplish) in the hyphae near the substratum.

Mucor griseo-lilacinus forms a drab gray to light drab (Ridgway) turf, 10–20 mm. tall on rice and an 8–19 mm. gray turf on grapefruit. It ferments dextrose but does not oxidize tyrosin. The cultures on rice exhibit a pinkish buff line (Ridgway) around the margins of the upper surface of the medium.

17. *MUCOR RAMANNIANUS* Moeller, Zeitschr. Forst- u. Jagdw. 35: 330. 1903

Forming on bread a dense purplish vinaceous to livid brown (Ridgway) turf, 1–2 mm. tall; *sporangiophores* 2–6 μ in diameter, simple or with one branch, septate; *sporangia* globose, 20–35 μ in diameter (extremes 40 μ), red; *sporangium* wall deliquescent; *columella* free, globose, 4–10 μ in diameter; *spores* minute, globose, subangular, tinged pink, 2–3 μ in diameter; *zygospores* not found (species presumably heterothallic).

This species was isolated from soil in coniferous woods and from decayed carrot. Nos. 2 and 62. Lendner says, "the coloration of the sporangia is probably due to interstitial substance," but examination of the spores with oil immersion has shown them to be distinctly tinged with pink.

Mucor Ramannianus varies but little. On bread and rice the height is 2 mm., but on grapefruit it does not exceed 0.5 mm. The color on rice is pale to light brownish vinaceous (Ridgway) while on grapefruit it is much brighter, light Corinthian red (Ridgway). This is the only species tested which did not ferment dextrose. Nor does it oxidize tyrosin.

18. *MUCOR SPINESCENS* Lendner, Bull. Herb. Boissier II. 8: 79. 1908; Les Mucorinées de la Suisse, 89. Berne, 1908

Forming on bread a dense, fuscous (Ridgway) turf, 1–3 mm. tall; *sporangiophores* 8–12 μ in diameter, simple or branched; *sporangia* globose, 74–98 μ in diameter (a few 50 μ), brownish

black, not transparent, encrusted with crystals about $2\ \mu$ long; *sporangium wall* deliquescent, leaving a large or small basal membrane; *columella* free, oval, pyriform, conical, or elongated, mostly oval apiculate, usually with one to five spines (exceptionally up to twelve) at the apex, although sometimes smooth, $21\text{--}43 \times 14\text{--}25\ \mu$, brown; *spores* globose (a few irregular), $5\text{--}8\ \mu$ (a few $4\ \mu$) in diameter, dark brown; *zygospores* not found (species presumably heterothallic).

This species was collected twice: from soil in greenhouse, and on decayed Brazil nut. Nos. 44 and 75. It is closely related to *Mucor plumbeus*, but differs in its habit of growth (*M. plumbeus* is 1 cm. tall), smaller sporangia, larger and smooth spores.

Mucor spinescens has never been found to exceed 8 mm. on any medium on which it has been grown and usually it is but from 2–5 mm. tall. On levulose and on dextrin gelatin it forms a dark brownish gray turf 8 mm. tall. On rice the turf is chaetura black (Ridgway) and only 3 mm. tall, while on grapefruit the turf is 4 mm. tall and fuscous (Ridgway). Fermentation of dextrose was obtained and the species is capable of slowly oxidizing tyrosin.

VI. DISCUSSION

I. TESTS FOR ZYGOSPORES

With the single exception of *Mucor proliferus*, zygospores were not found in any cultures of the heterothallic species studied. This is accounted for by the fact that single spore cultures formed the starting point for the study of every number isolated. Consequently it was deemed necessary to test the various collections of the same and of closely related species for zygospore production. In a preliminary set glucose gelatin was used, but in the final experiments Blakeslee's agar, the formula of which has been given, was used. Petri dishes were inoculated with four numbers of mucors and the cultures were examined when growth had resulted in a contact of the hyphae of all the four numbers. With the exception of *Mucor spinescens*, *M. sphaerosporus*, and Nos. 9 and 32 (*M. abundans*), all of the species collected were tested. In all about one hundred fifty different pairs of combinations were used, but the results proved negative in every case.

2. TAXONOMIC CHARACTERS

As has already been stated in the taxonomic division of the work, the author has disregarded some of the usage of past writers in the compilation of his key and specific descriptions. This has been done only after careful consideration and the subsequent belief that, by so doing, matters might be simplified and put on a surer basis than heretofore. Fischer (1892) regarded the grouping of the genus *Mucor* into sections according to branching "nur als eine provisorische Zusammenstellung." Yet Lendner (1908), Hagem (1908), and Jensen (1912) use the same method of separation, and as a result we find that there is considerable confusion and disagreement. To show this more clearly let us consider a few cases. *Mucor strictus* Hagem was placed by its author with the unbranched forms, but Lendner considers that it belongs in the *Cymo-Mucor* group and places it accordingly. *Mucor sphaerosporus* Hagem and *M. griseo-cyanus* Hagem, although classed by Hagem in the *Racemo-Mucor* group, are transferred to the cymose group by Lendner. *Mucor hiemalis* Wehmer, which Hagem calls a *Racemo-Mucor*, is held by Lendner to belong to the unbranched forms. *Mucor silvaticus* Hagem, placed in the *Cymo-Mucor* group by its author, is transferred to the *Racemo-Mucor* group by Lendner. Thus it appears, not only that the terms racemose and cymose, as applied to the branching in this genus, are interpreted by different authors in various ways but also that authors are disagreed as to whether forms are to be considered as simple or branched.

It has been the writer's experience that a mucor which never possesses a branched sporangiophore is a rare occurrence; for a careful search of the culture will usually reveal some branches which are likely to be overlooked, since they are near the substratum. Lendner (1908, p. 55) points out this difficulty. Practically it amounts to the necessity of deciding whether or not branching, if found, is abnormal. The writer believes this to be too difficult, as his work on the group has proved. Thus this means of separation has been avoided in the key and descriptions which this work contains.

Lendner (*l.c.*) describes the *Racemo-Mucor* group as follows: "The filament is early terminated by a sporangium, then branches arise

along the principal sporangiophore and never surpass it. This group comprises the species usually little branched." The *Cymo-Mucor* group is defined by him thus: "There is formed below the terminal sporangium a second branch surpassing the first, then on this second there arises a third which surpasses the second. The insertion of the ramifications is usually alternating; as a result there is produced a very characteristic zig-zag appearance." Hagem gives no explanation of his use of these terms, but it appears from his figures and descriptions that in some cases he departs from the usage of past writers. For example, he classifies *Mucor sphaerosporus* and *M. griseo-cyanus* as racemously branched, although his figures show that Lendner follows past usage in referring them to the cymose group of *Mucor*. Thus we have confusion arising from opposing conceptions of terms. It will be necessary to consider the terms applied to branching.

According to Sachs (1874), De Bary (1887), Schneider (1905), and Strasburger (1912) the two kinds of branching are monopodial and dichotomous; Jost (1907), on the contrary, uses the terms lateral branching and dichotomy. As we are not concerned with the latter we shall consider only the monopodium.

In the monopodium there is present a central axis with a growing point at its apex containing the apical cell. Branching in the monopodium, unlike the process in the dichotomy where a division of the apical cell results in a forking of the main axis, takes place by the development of axillary buds situated near or at some distance from the growing point of the stem. These lateral branches develop by the growth of apical cells. When the lateral branches remain shorter than the persistent main axis a racemose type of branching is evident. When, on the contrary, one or more lateral branches exceed the main axis, sometimes even assuming a central position, a cymose system of branching results. See Sachs (1874, p. 183). This applies in general to the higher plants.

According to Brefeld (1872), the germination of a spore of *Mucor Mucedo*, which may be regarded as typical for the genus, takes place in the following manner: the spore swells and there are produced one or several germ tubes which grow very rapidly and soon begin to branch in all directions, so that an irregularly much-branched thallus is produced. It should be noted that there

is no differentiation of the plant body into a specialized apical cell, such as is found in the higher plants. There may be, however, a correlation between the relatively simple plant body and the lack of a fixed branching system.

The vegetative condition may continue for a brief period or indefinitely, depending upon experimental conditions. Under usual laboratory conditions the vegetative period is short (twenty-four to thirty-six hours), and sporangiophores are produced as perpendicular branches arising from the thallus. In some species the growth of the sporangiophore stops with the formation of the apical sporangium; in other species, after the formation of a terminal sporangium, growth starts again, with the production of a lateral branch from some part of the sporangiophore, and continues until a sporangium is formed at the tip of this branch. On one hypha or branch the same process may be again repeated. (De Bary, 1887, p. 46.)

This account of the development of the sporangiophore apparently does not harmonize with De Bary's (1887) statement that "both growth and branching follow the laws which prevail generally in the vegetable kingdom." For it may be said that a comparison of the development of branching systems in the higher plants with those in the genus *Mucor* shows little similarity between them. Although, perhaps, the stems and inflorescences of the higher plants may be analogous to the sporangiophores and sporangia of *Mucor*, it can scarcely be maintained that there exists a homology between them. It appears then advisable not to apply the terms used to describe the branching of the higher plants to the sporangiophores of *Mucor*. Even if the writer's views on this matter can not be accepted, the impracticability of using the terms is sufficient reason for discarding them.

The characters which experience has proven reliable for specific determination are as follows: turf, columella, spores, sporangium, sporangium wall, and chlamydo-spores. These are given in the relative order of their importance. The height, color, and nature of the turf must be considered. Inasmuch as the term turf includes only the aerial part of the plant, the height of the turf is the length of the sporangiophores, and is expressed either in millimeters or in centimeters. Contrary to current opinion, there is

rather a wide range of color in the genus *Mucor*, varying from palest gray (almost white), through yellow and red to dark gray, brown, or black. Ridgway (1912) has been used as a color standard throughout the work. The nature of the turf is either loose, in which case it usually collapses with age, or compact, when it remains erect even on the drying out of the culture.

The relation of the sporangium wall to the columella, as well as the shape and size of the latter, is important. The word "free" has been used to designate the condition in which the sporangium wall is separate from the columella and is attached to the sporangiophore at the base of the columella; whereas the term "adnate" has been used in cases where the sporangium wall is adherent to the columella at its broadened base. (Cf. "nicht aufsitzend" or "libre" and "aufsitzend" or "susjacente.") In some species, especially those having globose or oval columellae, the shape is constant; in others a wide variation in shape and size of columellae is found. When the latter is true, the small columellae are mostly uniformly globose or oval; the large columellae, on the contrary, exhibit a strong tendency to a different shape. Thus in the descriptions when the shape of the columella is given as "oval to pyriform" it is to be understood that the larger columellae are mostly pyriform. In a few species, for example *Mucor varians*, the columellae are extremely variable and run the gamut of all the shapes.

In a consideration of the spores the shape and size must be noticed, and we find the spores either uniform or variable. If uniform, the shape may be globose, oval, elliptical, etc.; if variable, some combination of the above-mentioned shapes together with irregular spores, subreniform, subfusiform, etc.

Within certain limits the size of the sporangium is dependable, i. e., the sporangia may be large (200–500 μ in diameter) or small (not exceeding 100 μ in diameter and usually 60–80 μ). The wall of the sporangium is also important, being either deliquescent, rupturing, or persistent.

A certain group of species of *Mucor* can be separated from the rest by the fact that chlamydospores are present in the sporangiophores. *Mucor racemosus* and *M. sphaerosporus* would be included in such a separation of species.

As has already been stated, sixty-six collections of the genus *Mucor* were made. These were studied carefully from uniform bread cultures made in the previously described manner, and from the data obtained they were tabulated according to their specific individuality. In this preliminary arrangement twenty-six different groups were obtained, which, by careful comparison, were reduced to twenty-four groups. Nine of these aggregates were, after a careful study, referred to four species, three of which were undescribed. Thus the sixty-six collections of *Mucor* were distributed through eighteen species.

In TABLE I two species, *Glomerula repens* and *Zygorhynchus Vuillemini*, have been excluded from *Mucor*, although Lendner includes both *Zygorhynchus* and *Glomerula* in that genus. He examined specimens of the former only. A study of *Glomerula repens*, from two separate collections, has convinced the writer that this species can not be placed under the genus *Mucor* because the hyphae may serve as stolons. For example, if the tip of a hypha touches the wall of the culture container, a cluster of rhizoid-like hyphae is formed, and often from this cluster sporangiophores are developed. Moreover, the general habit of growth is unlike that of the species of *Mucor*. An increase in lack of sporangia production often results in a cottony, dense, sterile mass of buff mycelium. *Zygorhynchus*, on account of its unequal suspensors, not to mention its very slight production of sporangia and abundant zygospore formation, should, in the writer's opinion, be kept as a separate genus.

3. EXPERIMENTAL

The experiments, in so far as their original purpose is concerned proved almost entirely negative. It was thought that striking cultural results might be obtained from the experiments which might form the basis for a physiological separation of species. Little of this kind was observed. On the contrary, the experiments showed that the genus *Mucor* is composed of a physiologically close group of species, exhibiting only minute cultural variations. Sometimes these differences were correlated with species, but sometimes they occurred sporadically. A concrete example of this latter phenomenon was the production of a yellow

color in or on the substratum. This was obtained on bread, on rice, and in maltose-peptone-tyrosin solution. It probably represents the storing up of excess food material, as a microscopic examination showed the color to be due to yellow globules in the hyphae; moreover, this color production occurred only in cultures with abundant food supply.

The results of the experiments with carbohydrates plus asparagin, on the one hand, and mineral salts (including ammonium nitrate), on the other, which show that the mucors grow much better in the first case than in the second, may, it is believed, offer some indication as to the reason why complex media (rolled oats, bread, rice, cornmeal, etc.) are better than simpler media.

Fermentation is, apparently, a more widespread process in this genus than has hitherto been supposed, knowledge of the forms which can produce this phenomenon being limited to some twenty species. Wehmer (1907) has given a clear and concise summary of the work published on the subject. The writer's results, positive except in one case, have added twelve species to the list.

Hagem (1910) found that tyrosin was oxidized by several species of *Mucor* and *Rhizopus*, with the production of a red or reddish brown solution. He thinks that this change is brought about by the enzyme tyrosinase. In the cases of *Mucor strictus*, *M. silvaticus*, *M. plumbeus* the color was pale red, in *M. racemosus* and *M. christianiensis*, dingy brownish red, but in *Rhizopus nigricans* and *R. nodosus* the solution was dark red. The writer's experiments showed that the solution was colored dark reddish brown, with the formation of a dark brown precipitate, by *Mucor griseosporus* and *M. coprophilus*. In the case of *Mucor proliferus*, *M. spinescens*, and *M. plumbeus* the solution was pale brown and a brownish black precipitate was observed. With *Glomerula repens* a brownish tinge to the solution was obtained, while the aerial growth was distinctive in that it was pinkish buff (Ridgway).

The objection might be raised that bread is a variable substance and therefore is unsuitable for a standard culture medium. A comparison of cultural results obtained, during the past three years, with bread obtained from different sources has proven this objection negligible. The bread used is the ordinary baker's

white bread, such as is readily obtainable at any grocery store. It is thought that the use of bread is simpler than employing such complex media as Lendner's "mout gelatinisé."

VII. SUMMARY

1. From over one hundred collections, thirty-seven species representing fourteen genera of the Mucorales have been obtained.

2. After having tried various substances, bread was adopted as a standard culture medium for taxonomic purposes.

3. The carbohydrates with regard to their availability as a source of food supply for the mucors, as exhibited by their growth, may be arranged as follows, the best being given first: levulose, dextrin, glucose, lactose, maltose, inulin, and saccharose.

4. Organic nitrogen compounds are better than ammonium nitrate.

5. Seventeen species of *Mucor* were found capable of fermenting dextrose-peptone solution.

6. *Mucor griseosporus* and *Mucor coprophilus* can oxidize tyrosin in a maltose-tyrosin-peptone solution, with the production of a red coloration of the solution and the formation of a dark brownish black precipitate.

7. The terms racemose and cymose should not be employed to describe branching in this group, because of the confusion which has arisen through their use, not to mention the lack of homology between a sporangiophore and a branch of one of the higher plants.

8. Sixty-six collections of the genus *Mucor* have been studied in great detail under uniform conditions in standard bread cultures, and they have been referred to nineteen species, six of which are new: *Mucor griseo-lilacinus*, *M. varians*, *M. coprophilus*, *M. aromaticus*, *M. griseosporus*, and *M. abundans*.

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Explanation of plates 17-20

PLATE 17

Mucor abundans Povah. 1. Sporangiophores showing various kinds of branching, about natural size. 2. Upper portion of sporangiophore showing branch detail, $\times 350$. 3. Lower portion of sporangiophore, $\times 170$. 4. Columellae, $\times 350$. 5. Spores, $\times 350$. 6. Chlamydospores from within substratum, $\times 75$.

Mucor aromaticus Povah. 7. Columellae, $\times 170$. 8. Swollen branched apex of sporangiophore, $\times 75$. 9. Almost mature sporangium, $\times 170$. 10. Spores, $\times 170$. 11. Sporangiophores about three fourths natural size.

PLATE 18

Mucor griseosporus Povah. 1. Sporangiophores about one half natural size. 2. Portion of sporangiophore showing detail of branching, $\times 170$. 3. Lateral sporangium, $\times 75$. 4. Columellae, $\times 170$. 5. Spores, $\times 350$.

Mucor griseo-lilacinus Povah. 6. Sporangiophores, $\times 3$. 7. Portion of sporangiophore showing insertion of branch, $\times 170$. 8. Apex of sporangiophore, $\times 170$. 9. Columellae, $\times 170$. 10. Spores, $\times 350$.

PLATE 19

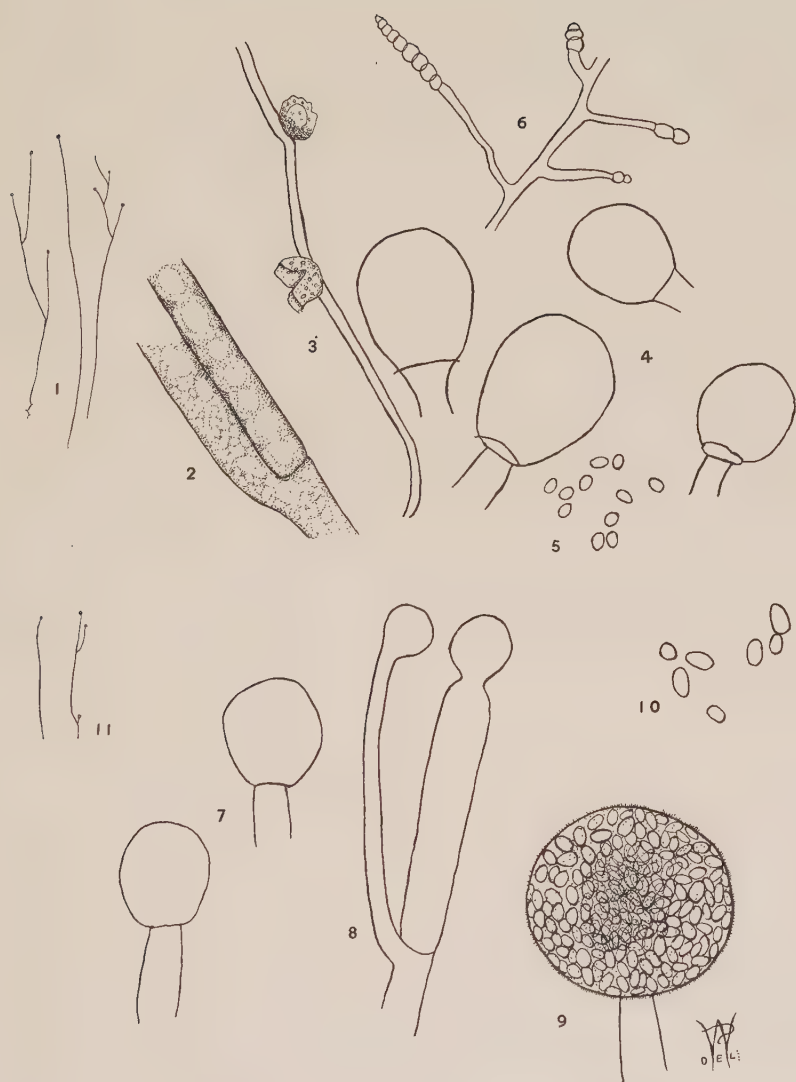
Mucor coprophilus Povah. 1. Sporangiophore, about one half natural size. 2. Columellae, $\times 170$. 3. Lateral deciduous sporangium, $\times 350$. 4. Spores from small lateral sporangia, $\times 350$. 5. Spores from large terminal sporangia, $\times 350$.

Mucor proliferus Schostak. 6, 7. Formation of gametes, $\times 75$. 8. Union of gametes, $\times 75$. 9. Immature zygospore, $\times 75$. 10. Mature zygospore, $\times 170$.

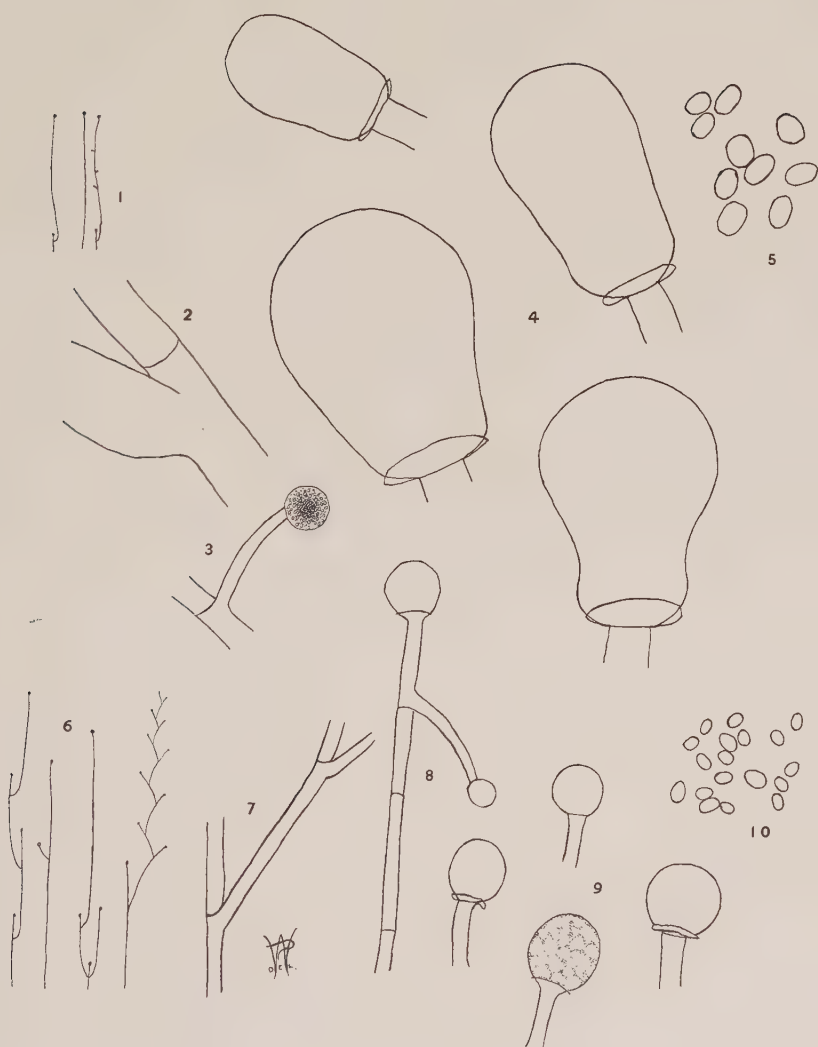
PLATE 20

Mucor varians Povah. 1. Sporangiophores, $\times 2$. 2. Columellae, $\times 350$. 3. Spores, $\times 350$. 4. Apex of sporangiophore, $\times 75$. 5. Proliferation of sporangiophore, $\times 75$. 6. Proliferation of columella, $\times 75$.

Mucor hiemalis Wehmer. 7. Sporangiophores, $\times 2$. 8. Portion of sporangiophore with branch insertion, $\times 350$. 9. Columellae, $\times 350$. 10. Spores, $\times 350$.



1-6. *MUCOR ABUNDANS* POVAH
 7-11. *MUCOR AROMATICUS* POVAH



1-5. *MUCOR GRISEOSPORUS* POVAH
 6-10. *MUCOR GRISEO-LILACINUS* POVAH



1-5. MUCOR COPROPHILUS POVAH
6-10. MUCOR PROLIFERUS SCHOSTAK.



1-6. *MUCOR VARIANS* POVAH
7-10. *MUCOR HIEMALIS* WEHMER

